

METALLURGIA

THE BRITISH JOURNAL OF METALS

The 'K.M.' meter, shown in the large picture, is robust in design and construction, and retains its initial accuracy throughout a long life.

The 'K.M.' is used for measurement of the

flow of steam, water, gas, oil, or any other fluid, whatever the quantity or pressure.

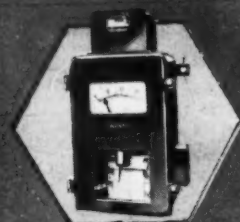
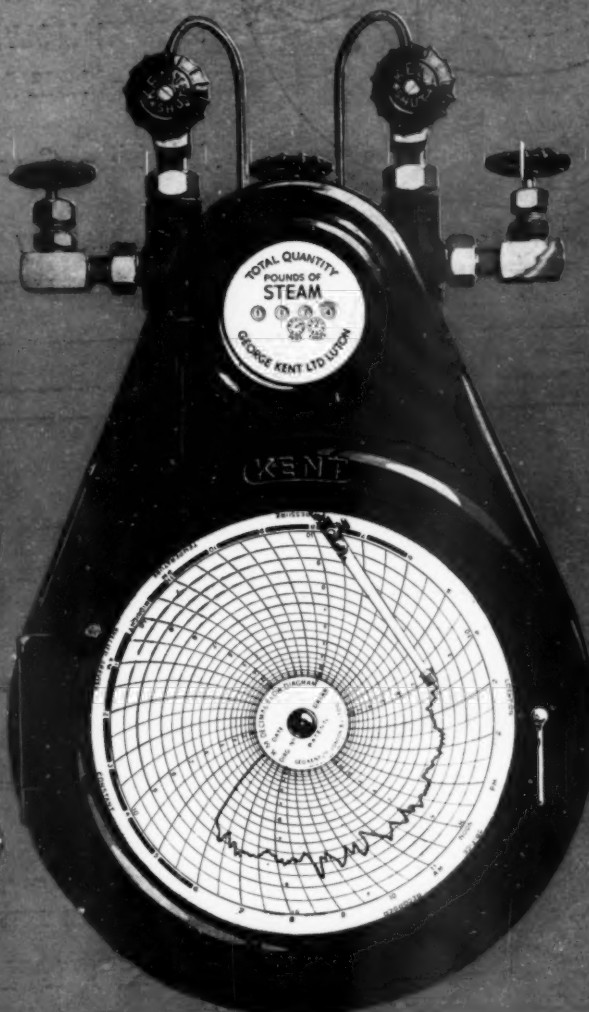
The number of Kent 'K.M.' meters that have been installed during the last 12 years runs into five figures.



RS/C Shunt Meter for steam or air.



Uniform cold-water Meter. (Sizes 2" to 6")



Ring type Air or Gas Flow Recorder.



Curved Tube Manometer for Air or Gas.

GEORGE KENT

GEORGE KENT LTD., LUTON & LONDON.



also
FERRO - MOLYBDENUM
CALCIUM-MOLYBDATE
SILICON-MOLYBDATE
IRON-MOLYBDATE

Reliable - Consistent

MADE BY

MINWORTH METALS LTD.

MINWORTH

BIRMINGHAM

SPECIAL REFRACTORY PRODUCTS

SILICA (VITREOSIL)

Low thermal expansion ; high electrical resistance ; improves refractory mixtures.

MAGNESIA

High electrical resistance, high thermal conductivity ; used in electric heaters and as high temperature refractory.

ALUMINA

High fusion point, great hardness ; used as a refractory or abrasive material.

REFRACTORY AND ELECTRICALLY INSULATING CEMENTS

THE THERMAL SYNDICATE LTD.

Head Office and Works : WALLSEND, NORTHUMBERLAND

London Depot : 12-14, Old Pye Street, Westminster, S.W.1

*Send for Free
Copy to-day*

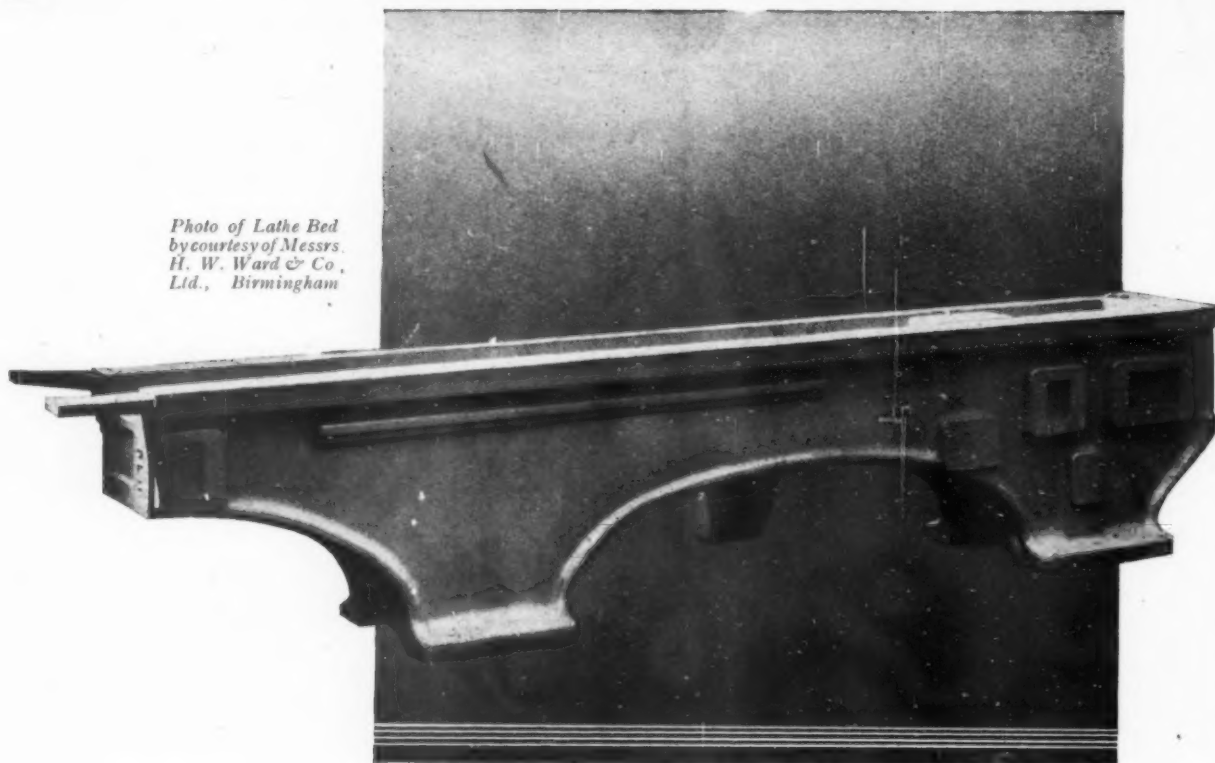


This pocket-book is issued in the interests of conservation of materials, and will be sent Free on application to all users of Crucibles. No effort should be spared to conserve essential materials.

THE CARBORUNDUM COMPANY LTD.
TRAFFORD PARK MANCHESTER 17.

Iron CASTINGS

*Photo of Lathe Bed
by courtesy of Messrs.
H. W. Ward & Co.
Ltd., Birmingham*



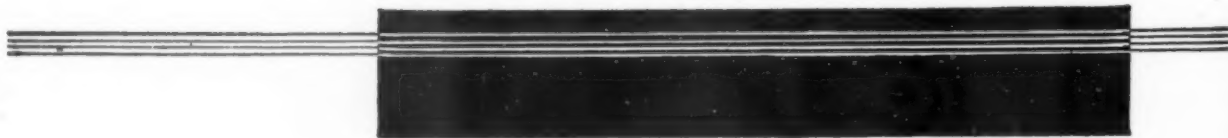
● Our modern equipment and up-to-date organisation enable us to produce the highest quality castings, that are reliable, accurate, have easy machining properties and can stand up to long service. We supply small light section castings and the heaviest machine tool and other castings up to 10 tons.

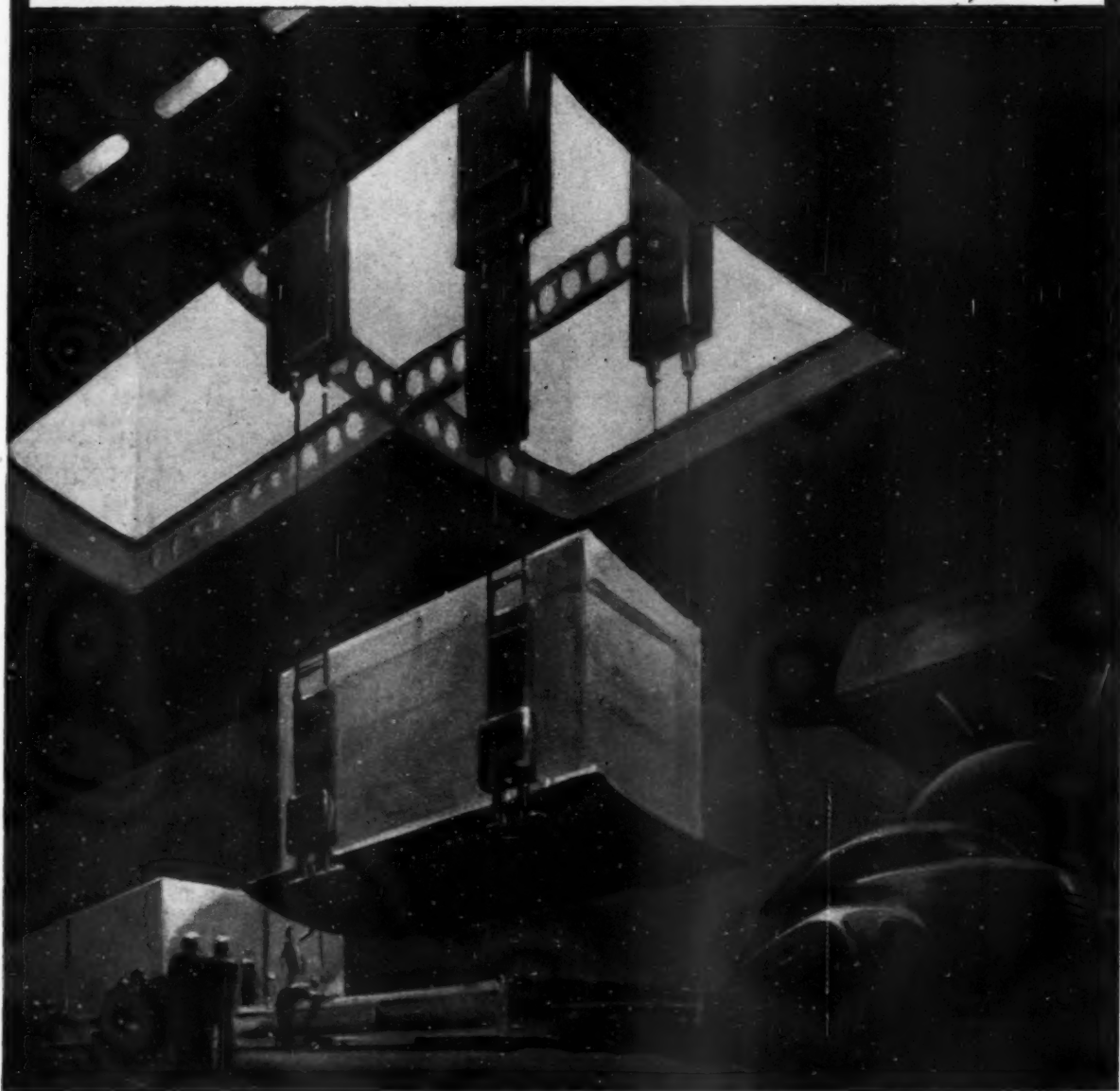
In addition to grey iron, nickel chromium iron and malleable iron, we can also give quick deliveries of castings of non-ferrous alloys, including aluminium bronze.

Your enquiries are invited.



RUDGE LITTLELY LTD.
Swan Village West Bromwich



BRITAIN'S MERCHANT AIR FLEET - *Loading-Up*

The availability of **HIDUMINIUM** in far greater quantities and range of forms will greatly influence the design and construction of all types of post-war cargo loading apparatus. No other materials compete with such alloys for strength to weight ratio, corrosion resistance and workability. Indispensable in war Hiduminium will play an equally vital part in peace. Technical data and advice on the use of these alloys are obtainable from the Development Department.

Trade spreads its wings with Hiduminium

HIGH DUTY ALLOYS LIMITED • SLOUGH

Gear Wheels



850 MAN HOURS PER 1000 WHEELS SAVED

These gear wheels*, used for lathe headstock and change wheel gears, are yet another example of the intricate shapes which can be die cast in zinc alloy. The production time for each wheel as a zinc alloy die casting is only a fraction of that entailed by previous manufacturing methods.

Compared with the previous processes used, die casting has effected a saving of 850 man hours per thousand in the case of the large wheel. Proportionate savings have been made in the production of the smaller wheels. As a result, skilled labour and machine tool capacity have been released for other vital work.

The most widely used of all metals for die casting, zinc alloys facilitate

the production of castings having the following outstanding advantages: **STRENGTH** : High mechanical properties enable their use for many stressed components in engineering assemblies. **COMPLEXITY** : Castings can be made practically to finished dimensions and require little or no machining; holes, external threads and often internal threads can be cast accurately. **ACCURACY** : Zinc alloys can be die cast to close dimensional tolerances which can be maintained throughout the useful life of the castings.

It is these properties, combined with low metal cost and long die life, which make zinc alloy die castings eminently suitable for innumerable applications — in peace as well as in war.

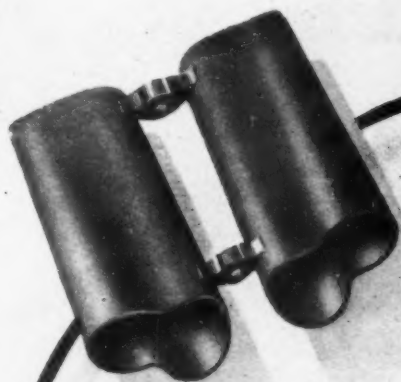
• • •

No. 9 in a series of advertisements issued by the Zinc Alloy Die Casters Association, an organisation formed by the industry to improve the technique of zinc alloy die casting and to promote a fuller appreciation of the properties and applications of the castings.

ZADCA

* Shown slightly reduced, they are pressure die cast in zinc alloy conforming to B.S. 1004.

The Lightest Structural Metal



THE LIGHTEST HOUSING FOR FIELD-GLASSES

The lightness of MAGNUMINIUM magnesium base alloys is evidenced by its pre-eminent suitability as a material from which to make field-glasses, telescopes, cameras, cine-film projectors and a host of other such portable instruments. Magnuminium is four times lighter than steel, possesses high strength/weight ratio, excellent machinability, and can be efficiently fabricated into finished parts. Technical data may be obtained from the Sales Department.

MAGNESIUM CASTINGS & PRODUCTS LTD · SLOUGH



MAGNUMINIUM

MAGNESIUM BASE ALLOYS

Commonwealth Carriers



Special alloy steels,
from perfect co-
ordination of science
and production shop,
are the Firth Brown
contribution to
scientific engineering.



THE PATH-FINDERS
OF
MODERN PROGRESS

FIRTH-BROWN SPECIAL ALLOY STEELS

THOS. FIRTH & JOHN BROWN LIMITED

"OVERHEADS"

in the post-war epoch will depend upon careful expenditure in **SELECTED** metals that may be relied upon to ensure maximum returns for a given capital outlay.

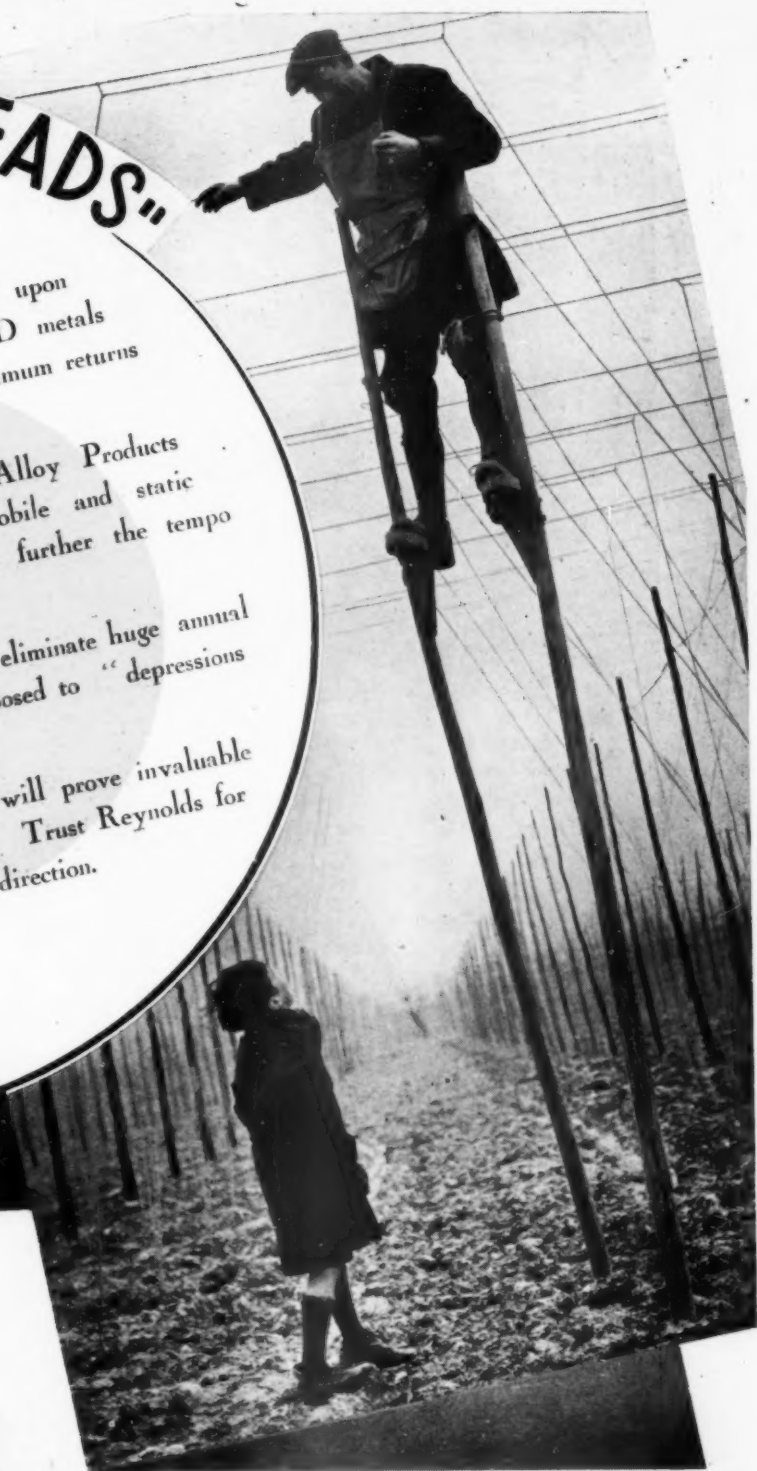
The lightness of Reynolds' Light Alloy Products will confer untold advantages to mobile and static Industrial Plant and speed up yet further the tempo of fast-moving machinery.

Their anti-corrosion properties alone eliminate huge annual repainting costs where metal is exposed to "depressions from Iceland."

In a hundred and one ways they will prove invaluable ingredients in Post-war Industry. Trust Reynolds for vigorous enterprise in **THAT** direction.



Photograph—Fox Photos.



REYNOLDS



TUBES·RODS·SECTIONS·SHEET & STRIP IN "HIDUMINIUM" ALUMINIUM ALLOYS

REYNOLDS TUBE CO. LTD. & REYNOLDS ROLLING MILLS LTD, BIRMINGHAM, II.

"Cronite"
REGD. TRADE MARK

**FOR
HIGH TEMPERATURE
SERVICE**

**THE NICKEL-
CHROMIUM
ALLOY**

**For Temperatures at which
other metals collapse**

HEAT RESISTING CASTINGS
OF ALL TYPES : CASE
HARDENING VESSELS
ROTARY RETORTS AND
MUFFLES : PYROMETER
PROTECTION SHEATHS

THE CRONITE FOUNDRY CO. LTD.

LAWRENCE ROAD, TOTTENHAM, LONDON, N.15

Phone
STAMFORD HILL 4237

CURRAN Continuous

*Spray
Pickling*

(PATENTS IN GREAT BRITAIN AND ABROAD)

BETTER PICKLING — QUICKER PICKLING
UNDER IDEAL CONDITIONS
NO ACID FUMES — NO MESS
SAVES LABOUR — SAVES SPACE

Whether your problems are in the present or Future we can help you NOW

WRITE FOR FULL PARTICULARS

CURRAN
OF CARDIFF



THE BEST ON TEST

CURRAN BROTHERS LTD · CARDIFF

also at NEW YORK and MONTREAL

SPECIALISTS IN CONTINUOUS FURNACE & PICKLING PLANT, ETC.

HEAT TREATMENT *Ovens* *for* LIGHT ALLOYS

The C.H.A.L. DIFFUSED CIRCULATION system of heating is incorporated in all C.H.A.L. Heat Treatment Ovens, and ensures that oven temperature is equal in all parts of the working space for any condition of loading. The temperature is maintained within close limits during the whole of the soaking period, and—an important feature of the critical ageing process—all parts of the load receive equal heat treatment.

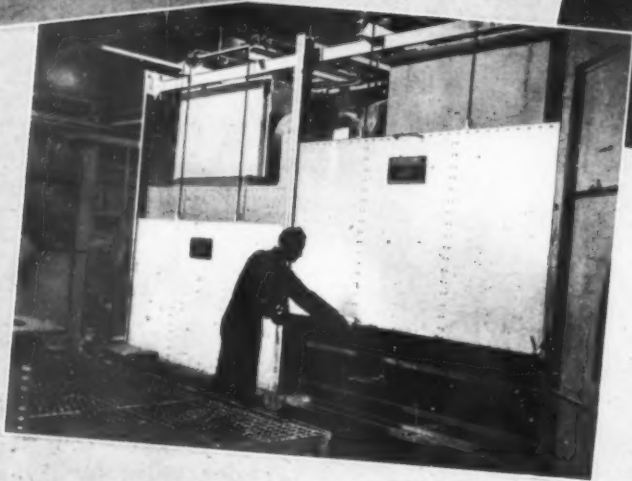
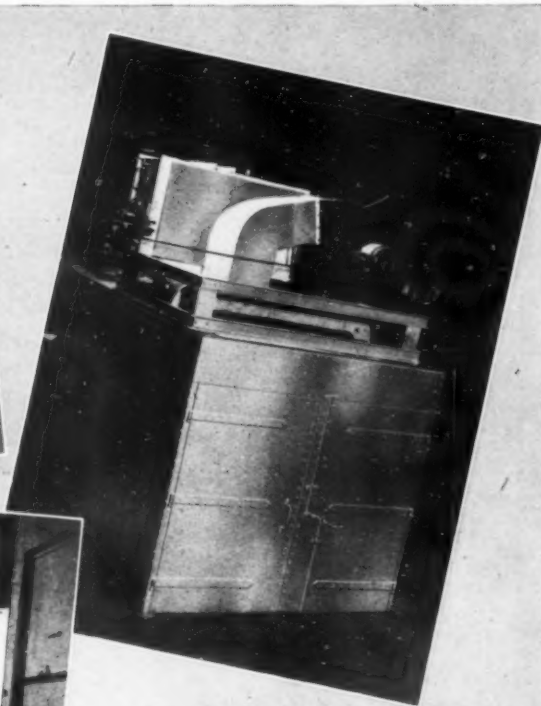
We have also developed a completely new design of oven for the tempering of Magnesium-Rich Castings. This oven is Direct Gas fired, employing air circulation. Oxidation and blistering is prevented without the necessity of a separate atmosphere generating unit.

We manufacture a wide range of ovens, of both batch and continuous types, and typical examples of our batch type light alloy ageing ovens are illustrated.

(Upper, left.) Direct gas-fired, air-circulated ageing oven for light alloy sheets. Doors are provided at each end and loading is by trolleys which travel through the oven.

(Lower, left.) Shelf loading type light alloy ageing oven, with rise and fall doors.

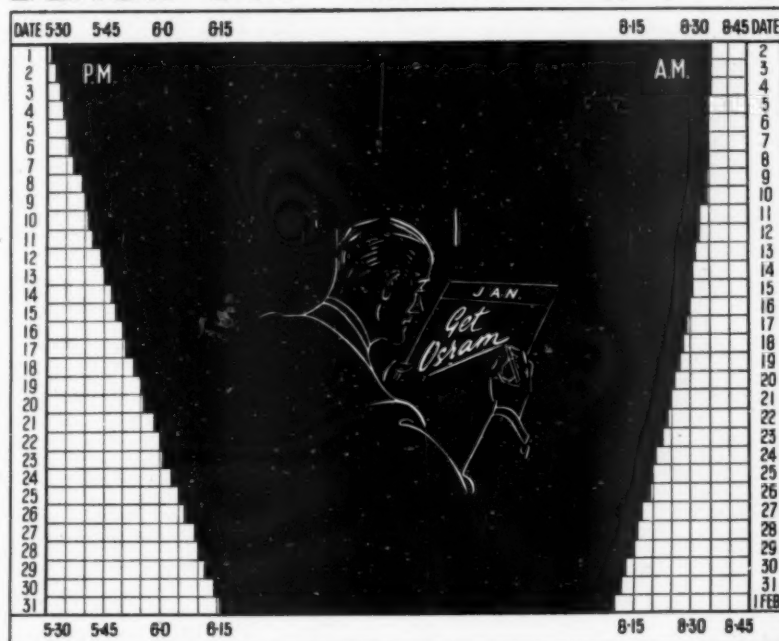
(Right.) A further example of a gas-fired air-circulated ageing oven. All C.H.A.L. heat treatment ovens incorporate the diffused circulation system already mentioned, and may be designed for firing by gas or electricity.



CONTROLLED HEAT & AIR LTD · CORNWALL ROAD · SMETHWICK

New Year Resolution

BLACK-OUT CHART FOR JANUARY



Reproduced from the Nautical Almanac by permission of the Controller of H.M. Stationery Office.

MOON PHASES



FIRST QTR.
JAN. 2nd.



FULL MOON
JAN. 10TH.



LAST QTR.
JAN. 18TH.



NEW MOON
JAN. 25TH.

★ Times shown are those for the London area.

You will strive more than ever to keep the wheels of output running smoothly and ever faster.

You will see that working conditions lack nothing that will contribute to the comfort and well-being of the workers.

Special care will you take with lighting — that essential and beneficial factor in every industrial plan.

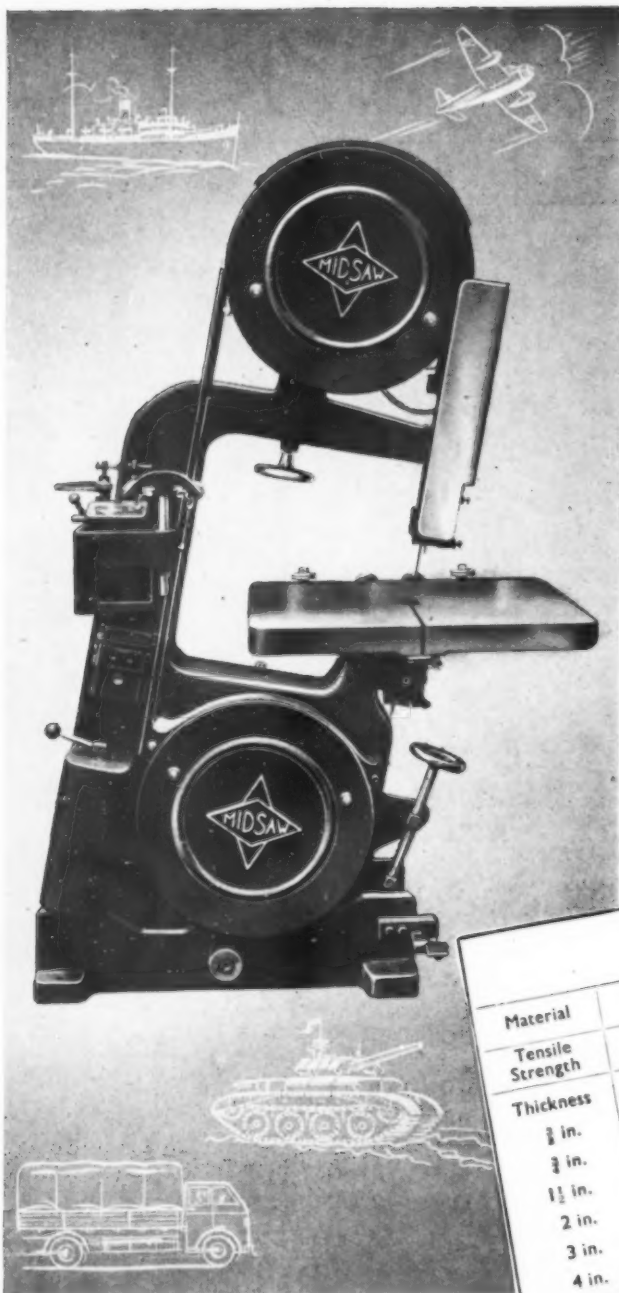
To make sure of reliable lighting service, you will resolve to make 1944 another OSRAM year.

Osram

THE WONDERFUL LAMP

Advt. of The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.





See what a MIDSAW can save . . .

THE chart set out below will keenly interest every manufacturer out for the highest economy in the production of Dies, Press Tools, Templates, Gauges and other Tool Room work.

MIDSAW, the Miracle Worker, saws and files the hardest modern metals, both regular and irregular shapes, with a speed and accuracy impossible by any other method, and—it achieves this with unskilled and inexperienced operators.

The MIDSAW Tool Room Bandsaw and Bandfile Machines cut out laborious drilling, chiselling, chipping and hand filing methods which put a brake on output and increase production costs. Our Technical Advice Service will be happy to advise you—write us.

CUTTING TIMES Per Inch Length of cut						
Material	Mild Steel		Carbon		Nickel Chrome Steel	
	30 tons		45 tons		65 tons	
Tensile Strength	Mins.	Secs.	Mins.	Secs.	Mins.	Secs.
Thickness						
$\frac{1}{2}$ in.		20		30		50
$\frac{3}{4}$ in.		35	1	15	1	10
1 in.		50	2	—	2	50
1½ in.	1	45	2	45	3	35
2 in.	2	—	3	45	5	45
3 in.	3	20			7	—
4 in.						



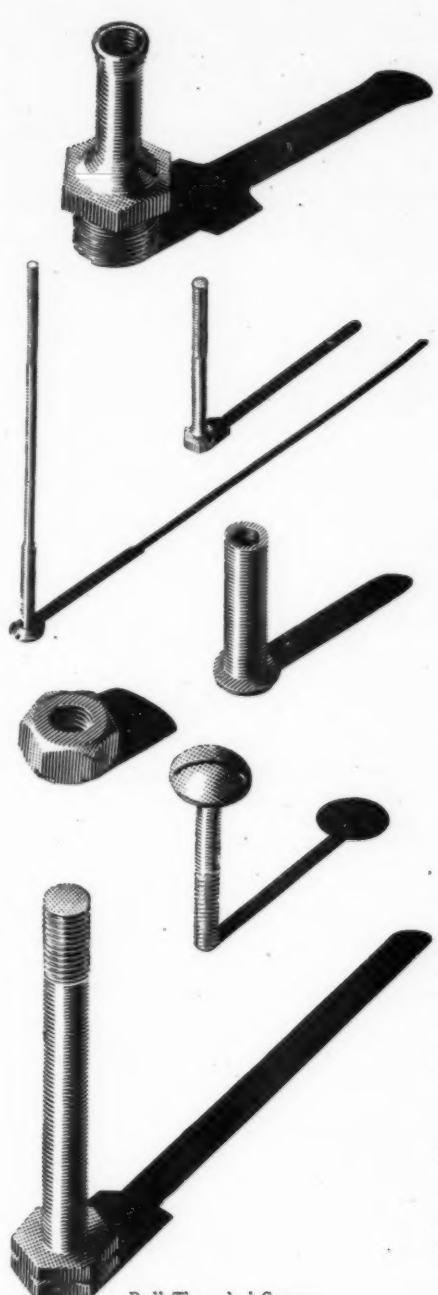
Write for our Illustrated Brochure of Metal Cutting Machines



THE MIDLAND SAW & TOOL CO. LIMITED

MIDSAW WORKS • POPE STREET • BIRMINGHAM.
Telegraphic Address - Midsaw Birmingham. Phone COLmore 4245/6

London Office: 24 UPPER PARK ROAD, KINGSTON ON THAMES
Phone: KINGSTON 4146. Telegrams: Morimil, Kingston on Thames



More than meets the eye

Small parts like Bolts and Screws, Rivets and Distance Pieces are not in the limelight—they do not meet the eye—but they are essential parts, and that's why the authorities have set a high standard for them. You know that's sound policy — you know that you have to use the best that is made. If you value the specialist's job that is right in every respect you will value Linreads.

Roll Threaded Screws
Solid & Tubular Rivets
Nuts, Bolts, etc., in all metals
Small Pressings
Auto and Capstan Turned Parts

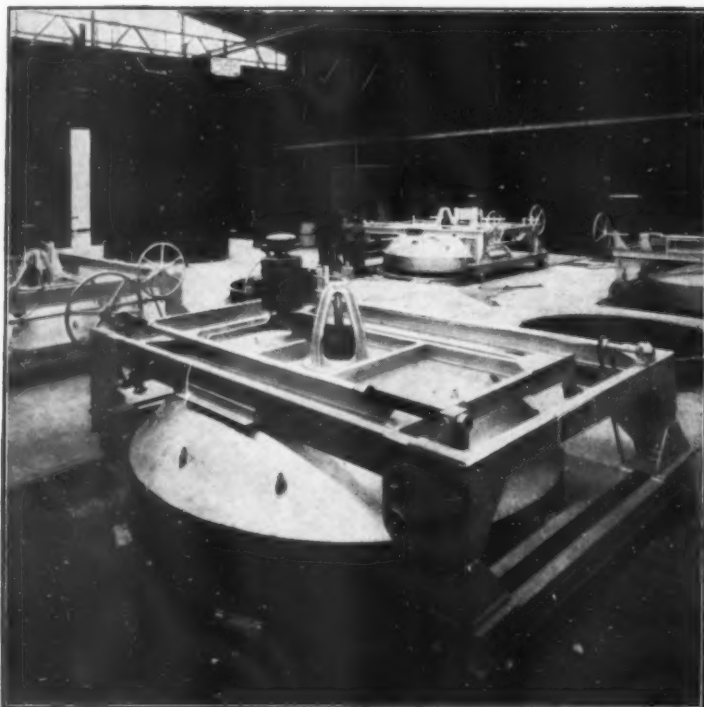
LINREAD LTD., STERLING WORKS, COX STREET,
BIRMINGHAM, 3. 'PHONE: CENTRAL 6121-2-3

Linread

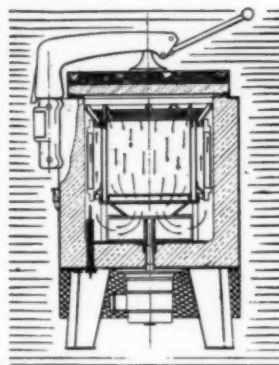
SPECIALISTS IN COLD FORGING

ECONOMICAL HEAT-TREATMENT OF NON-FERROUS METALS

FORCED AIR CIRCULATION FURNACES



Besides rapid heating, the ideal plant for modern requirements should provide absolute uniformity of temperature with precise control of treatment in respect of both temperature and time. In addition, simplicity of operation, low running costs, inexpensive maintenance, and safe and cleanly working conditions are obviously desirable. These features are inherent in Wild-Barfield Electric Furnaces. Especially suitable for tempering, secondary hardening of high speed steels, the heat-treatment of aluminium alloys and other non-ferrous materials.



Diagrammatical representation illustrating the principles of the Vertical Forced Air Circulation Furnace.

FURNACES FOR ALL HEAT-TREATMENT OPERATIONS



WILD-BARFIELD ELECTRIC FURNACES LTD.
ELECURN WORKS, WATFORD BY-PASS, WATFORD, HERTS

Telephone: WATFORD 6094 (4 lines). Telegrams: ELECURN, WATFORD

A handful of sound judgment



We feel we can justly claim that any firm deciding to use Wimet Tips on their cutting tools can be said to be showing the soundest judgment, and they could not make a wiser and more profitable decision, for is it not a fact that Wimet Tips have become the standard by which all others are judged? Made by us, the pioneers in the manufacture of carbide tools in this country, from the finest brand of tool metal ever produced, Wimet Tips have no equal. Making for greater speed and accuracy as they do, they cannot fail to have a most stimulating effect on production, and their use will prove a very effective economy, due to their long working life between regrinds. Indeed anyone of sound judgment would never choose to use any other tips but Wimet.

A.C. Wickman
LIMITED

• COVENTRY • ENGLAND •

LONDON BRISTOL BIRMINGHAM MANCHESTER LEEDS GLASGOW NEWCASTLE

IMMEDIATE DELIVERY OF STANDARD TIPS FROM STOCK

STEIN

Basic Refractories

JOHN G. STEIN & CO. LTD.

JOHN G. STEIN & CO. LTD.

TYPICAL OPEN-HEARTH FURNACE with fully sloping back wall

STEIN KM

STEIN CHROME

STEIN MAGNESITE

Four worthwhile applications of "STEIN KM" Chrome Magnesite Brick in the Open Hearth Furnace are—

- 1 As a CENTRAL PANEL in the Back Wall over the tap hole, to reduce the scouring action of the siliceous wash.
- 2 In the FURNACE HEARTH, similar to U.S.A. practice. One user has just converted his fourth furnace in the last three years to a "STEIN KM/STEIN CHROME" Bottom, using Magnesite only in the tap-hole area.
- 3 A FACING to the BLOCKS which serves to maintain the direction of the flame throughout the furnace campaign.
- 4 In the WING WALLS, where "STEIN KM" gives protection to the Back and Front linings.

JOHN G. STEIN & CO. LTD.
GLASGOW



6687 B

Many factories in this country—too many—are still without Power Trucks. In these factories Power Trucks would

- Speed up movement of material and work in progress
- enable ONE girl to do the work usually done by TEN men
- cut out intermediate handling so that Movement can ANTICIPATE Processing.

Write for particulars of the Douglas Truck-Stillage system—the Advanced Striking Force of the Factory Front.

Douglas

Regd. Trade Mark.

INDUSTRIAL Power TRUCK

DOUGLAS (KINGSWOOD) LTD., P.O. Box 1T, KINGSWOOD, BRISTOL. (Tel. 73013)
Export Div.: Engineering & Aviation Exports, Ltd., 50, Pall Mall, S.W. 1. (Tel. ABBey 6210. Cables 'Aerogal,' London.

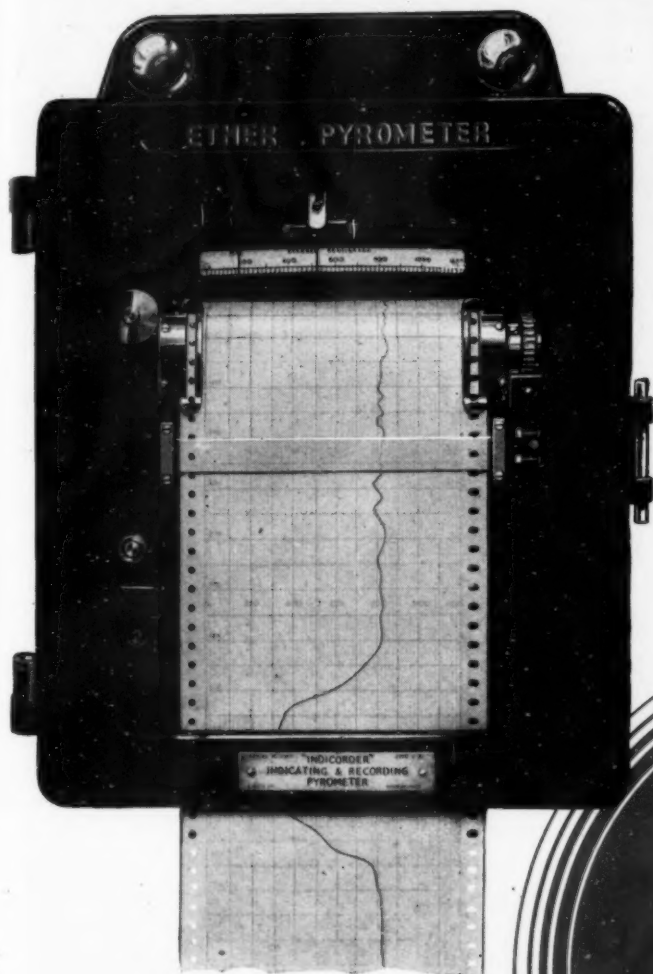
*"Oh! Pardon me for this intrusion;
But ...
Have you seen this fine extrusion?"*



FOR WROUGHT LIGHT ALLOY EXTRUSIONS SHEET AND STRIP

BIRMETALS LIMITED · BIRMINGHAM · 32

ETHER RECORDING AND CONTROLLING PYROMETERS



The Ether "Indicorder" Recording Controller provides an accurate means of recording and controlling temperatures with accuracy by a single instrument.

This combination of recorder and controller in one instrument provides a definite check on the limits of control achieved and a continuous record of treatment given to a specified batch of work, both in time and temperature.

Used all over the World
for Heat Treatment of
Aircraft and Armament

Illustrated list free on request

ETHER
Automatic
**TEMPERATURE
CONTROL**

Accuracy beyond human achievement

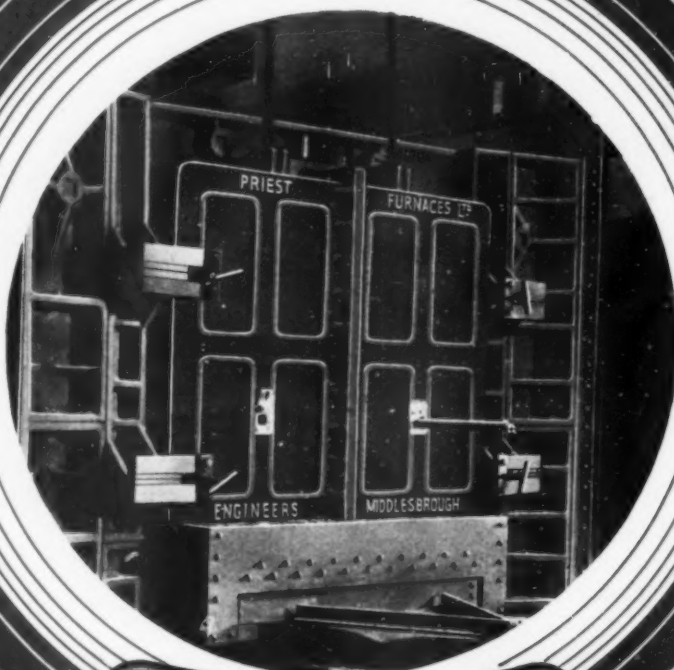
ETHER LTD.

ERDINGTON • BIRMINGHAM 24

Telephone

EAST 0276-7

The economical heat of industry!



PRIEST

FURNACES

Priest Furnaces represent the highest technique of furnace design and construction; for whatever fuel and process, they will be found to give the utmost precision in control, economy, high throughput and low maintenance.

PRIEST FURNACES LIMITED • LONGLANDS • MIDDLESBROUGH •

82-87 TELEGRAPH BUILDINGS • HIGH STREET • SHEFFIELD

GREETINGS

To
FRIENDS
OLD *and* NEW
THE SEASONS
COMPLIMENTS

ALUMINIUM
ALLOYS

LIGHT ALLOY PRODUCTS CO. (BIRMINGHAM) LTD

BROCKHOUSE
FOR
HEAT RESISTING
STEELS



*"That
reminds me
PUT A NOTE ON MY PAD -
'Phone"*

BROCKHOUSE
THE NAME THAT CARRIES WEIGHT

The activities of the BROCKHOUSE Organisation cover such a wide field that there are but few problems in the industrial world that would not be of direct interest to one or another of their numerous branches.

Brockhouse Castings, Ltd., are concerned largely with the production of

HEAT RESISTING STEELS

**BROCKHOUSE
CASTINGS LTD**

WEDNESFIELD
WOLVERHAMPTON

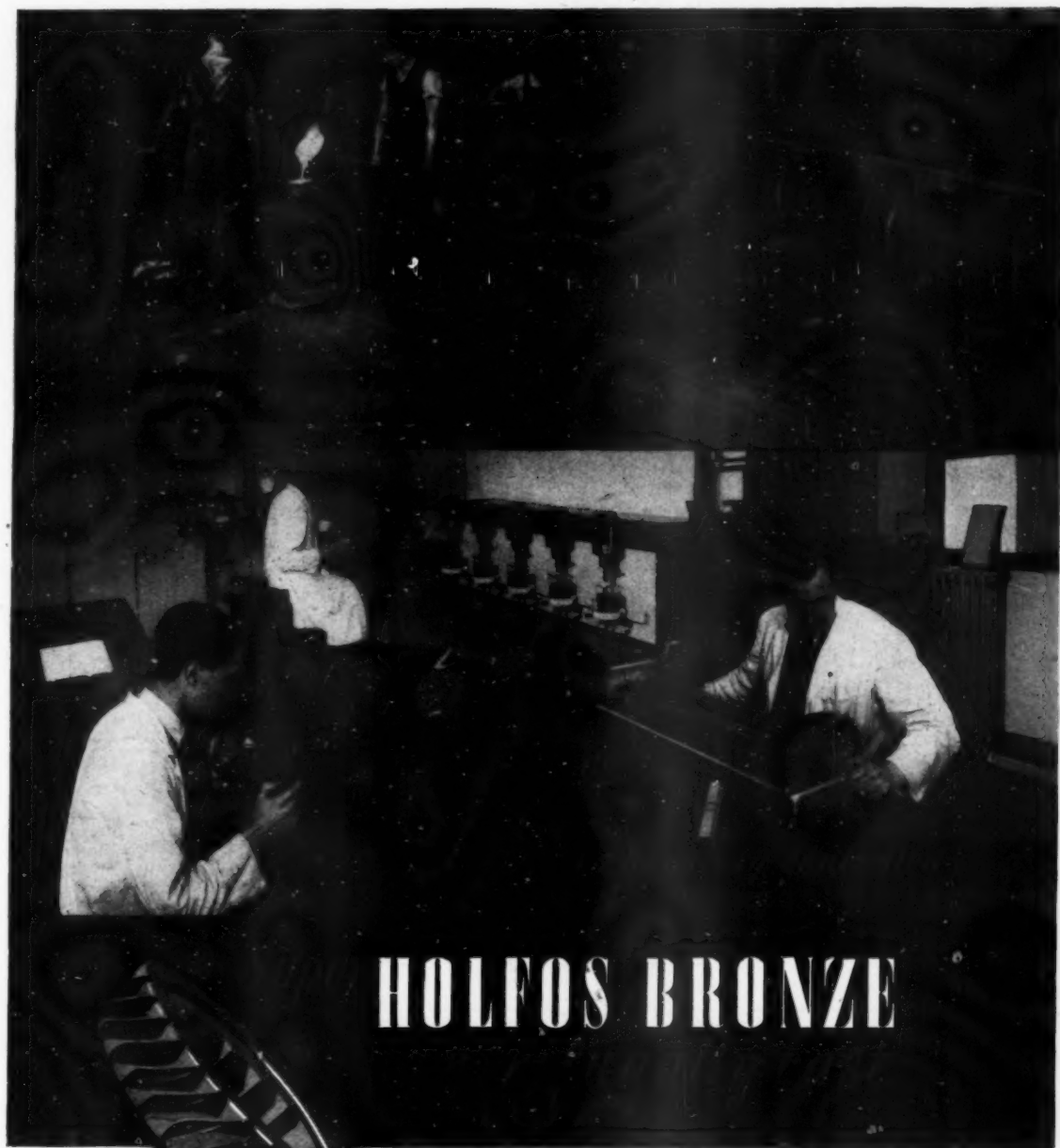
'Phone : Fallings Park 31221

for Heat-treatment Furnaces, Pyrometer Sheaths,
Annealing Pots, Fuel Burners, etc., etc.

Consult Brockhouse on all matters pertaining to
Heat-resisting Steels, and they will advise and
supply the requisite alloys.

London Office : MORLEY HALL, ST. GEORGE STREET, LONDON, W.1.

Telephone : Mayfair 8783-8.



HOLFOS BRONZE



JOHN HOLROYD & CO LIMITED
ROPE STREET • ROCHDALE



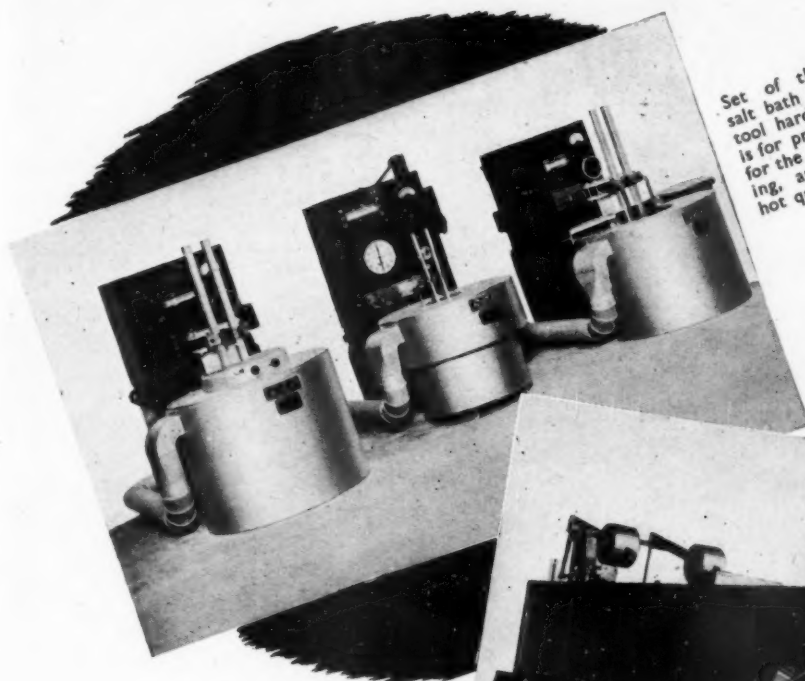
Produced under our own patented Austenitic Core Process which gives symmetrical hole of maximum smoothness. Round, Octagon, Hexagon and Square Sections, and in sizes ranging from $\frac{3}{8}$ " to 3" diameter, holes $\frac{3}{16}$ " to $\frac{1}{2}$ " diameter, depending on outside diameter—in lengths up to 40'—and in any quantity including High Tensile and Heat and Rust-Resisting Steels. Also supplied with bored holes outside diameters $1\frac{1}{2}$ " to 9", inside diameters minimum $\frac{3}{4}$ " and larger, lengths up to 20' depending on outside diameters.

ALLOY STEELS

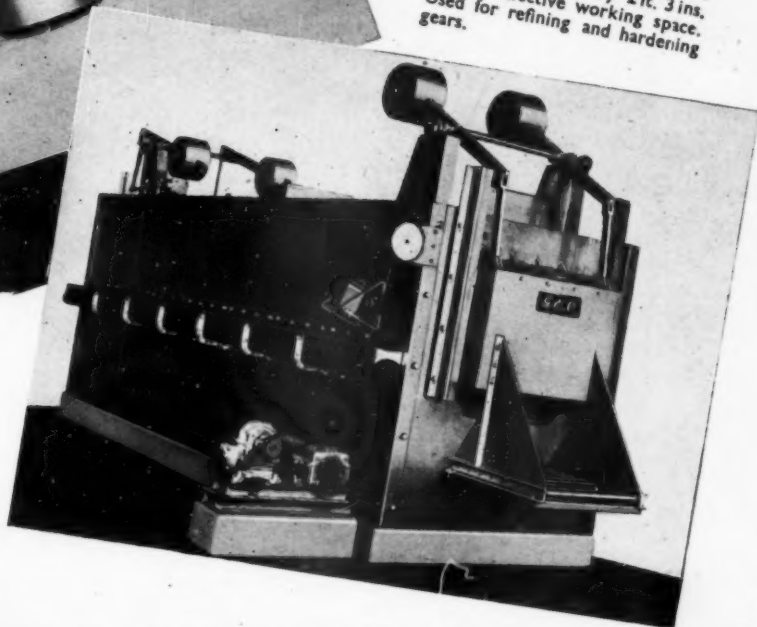
In black or bright finish, heat treated or untreated condition. "DUNELT" Specially Selected Steels can be supplied to meet the requirements of the latest "Standard" Service Specifications.

Manufacturers of Rotary Louvre Drying Plant.

DUNFORD & ELLIOTT (SHEFFIELD) LTD., Attercliffe Wharf Works, Sheffield 9.
 LONDON OFFICE: 54 VICTORIA STREET, S.W.1 BIRMINGHAM OFFICE: 25 BURLINGTON CHAMBERS, 118, NEW STREET



Set of three electrode type salt bath furnaces for high-speed tool hardening. Furnace on left is for preheating, middle furnace for the high temperature hardening, and that on the right for hot quenching.



100 kW continuous roller hearth type furnace, 15 ft. by 2 ft. 3 ins. by 1 ft. effective working space. Used for refining and hardening gears.

S.E.C.

ELECTRIC FURNACES

for every heat treatment process

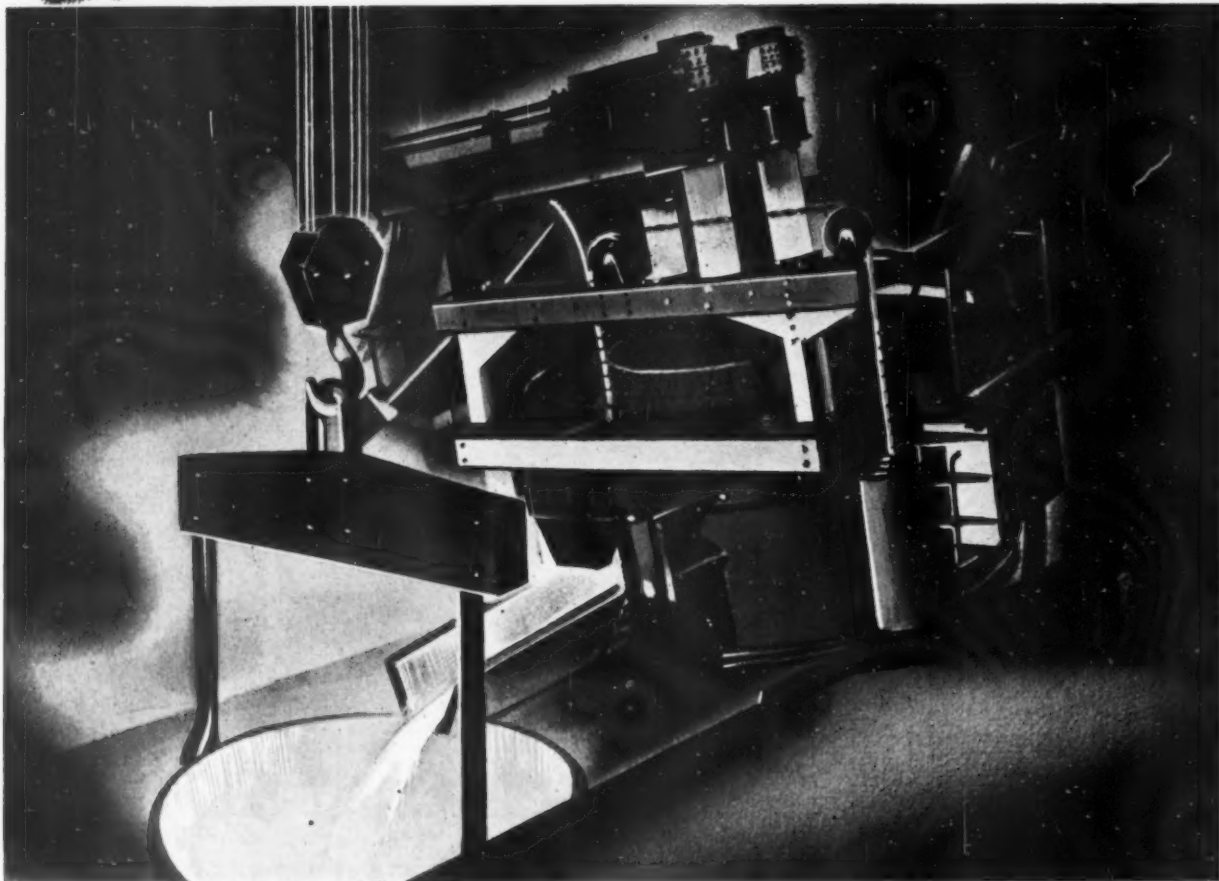
These are another two examples of the various G.E.C. Furnaces which are playing such a vital part in engineering production to-day.

They represent developments that are capable of very wide application to industrial heat-treatment requirements.

Consult the S.E.C. on all furnace requirements.



IN THE VANGUARD OF PROGRESS....



The progressive development of Electric Arc Steel Furnace practice has been appreciably aided by the dependability and efficiency of Graphite Electrodes (Acheson Process) under the most rigorous conditions of operation.

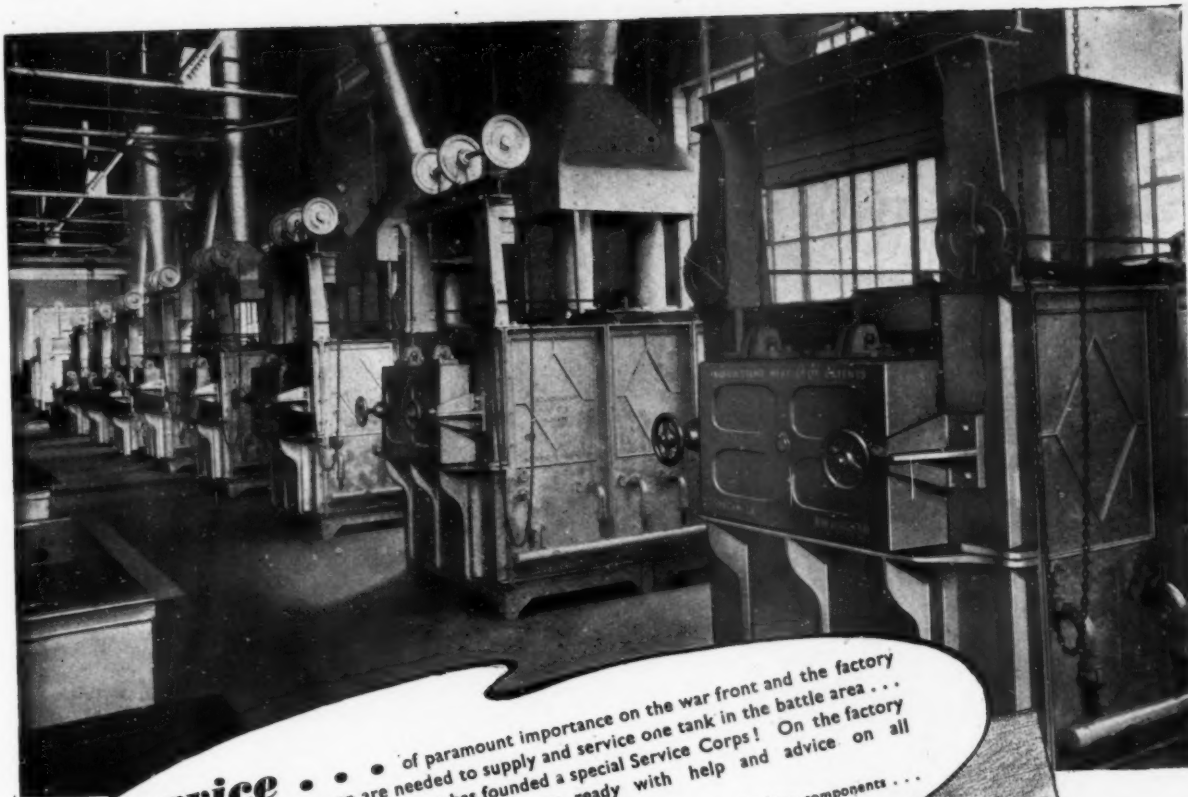


BRITISH ACHESON ELECTRODES LTD

GRANGE MILL, LANE · WINCOBANK · SHEFFIELD

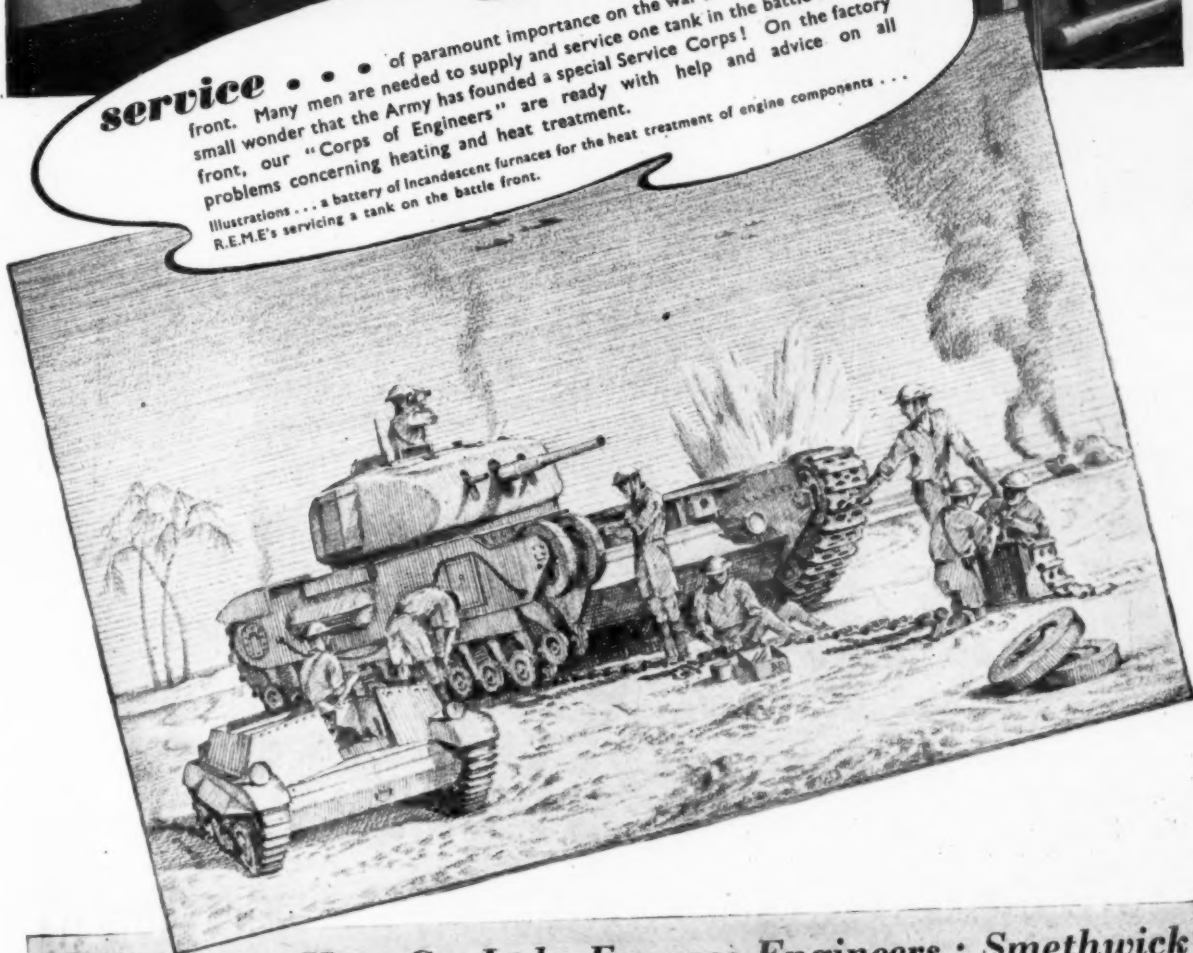
Tel: Rotherham 1836 (4 lines)

Grams Electrodes Sheffield.



service . . . of paramount importance on the war front and the factory front. Many men are needed to supply and service one tank in the battle area . . . small wonder that the Army has founded a special Service Corps! On the factory front, our "Corps of Engineers" are ready with help and advice on all problems concerning heating and heat treatment.

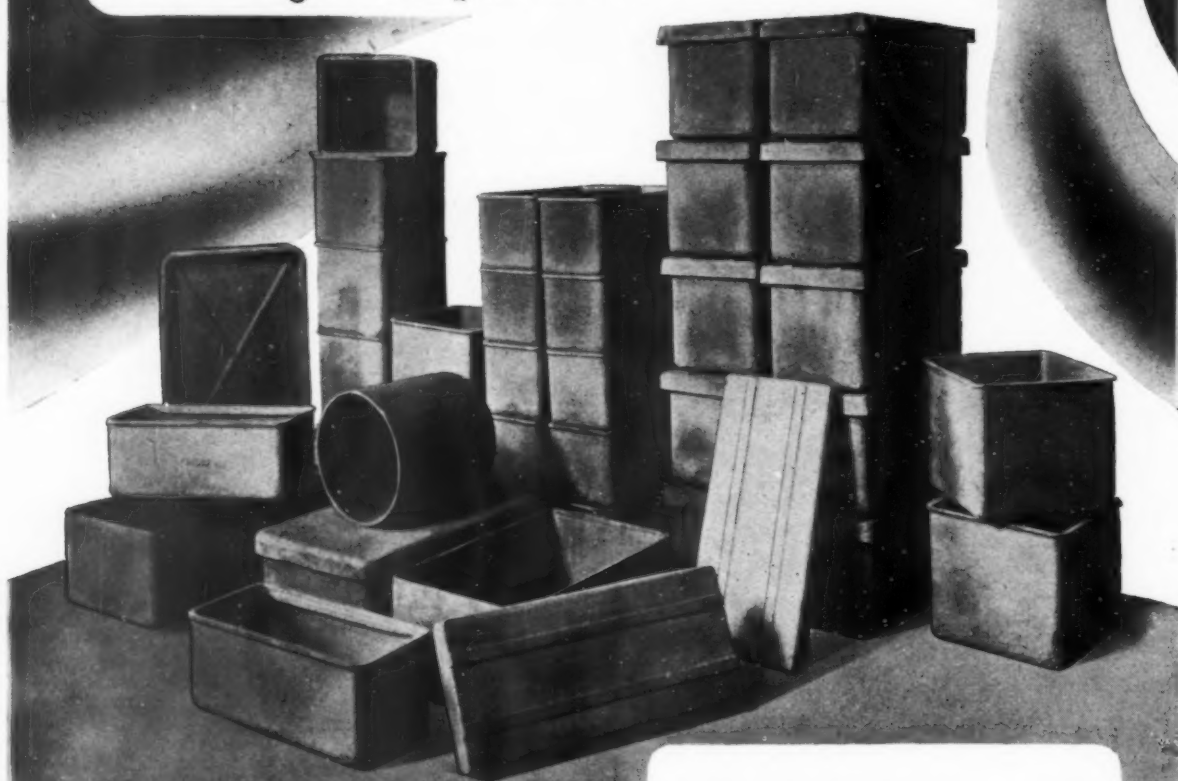
Illustrations . . . a battery of Incandescent furnaces for the heat treatment of engine components . . . R.E.M.E's servicing a tank on the battle front.



Incandescent Heat Co. Ltd • Furnace Engineers • Smethwick

..CASE-HARDENING AND ANNEALING BOXES

in
'PIREKS'
ALLOYS
for high temperatures



DARWINS
FINE STEELS
made by craftsmen

Casehardening and annealing boxes in a wide variety of stock patterns and to special design are available in the various grades of "Pireks" Alloys, for all conditions of temperature and service. Write for particulars of "Pireks" Alloys and list of patterns in stock.

DARWINS LIMITED · FITZWILLIAM WORKS · SHEFFIELD

EXPORT DIVISION: DARWINS TOLEDO OVERSEAS LIMITED, SHEFFIELD.

C.H.3a.



ALUMINIUM ALLOY CASTINGS

JOHN DALE LTD., BRUNSWICK PARK RD., NEW SOUTHGATE, LONDON, N.11

Telephone and Telegrams :—LONDON—ENTERprise 1167-8-9



CASTING-PIT REFRACTORIES

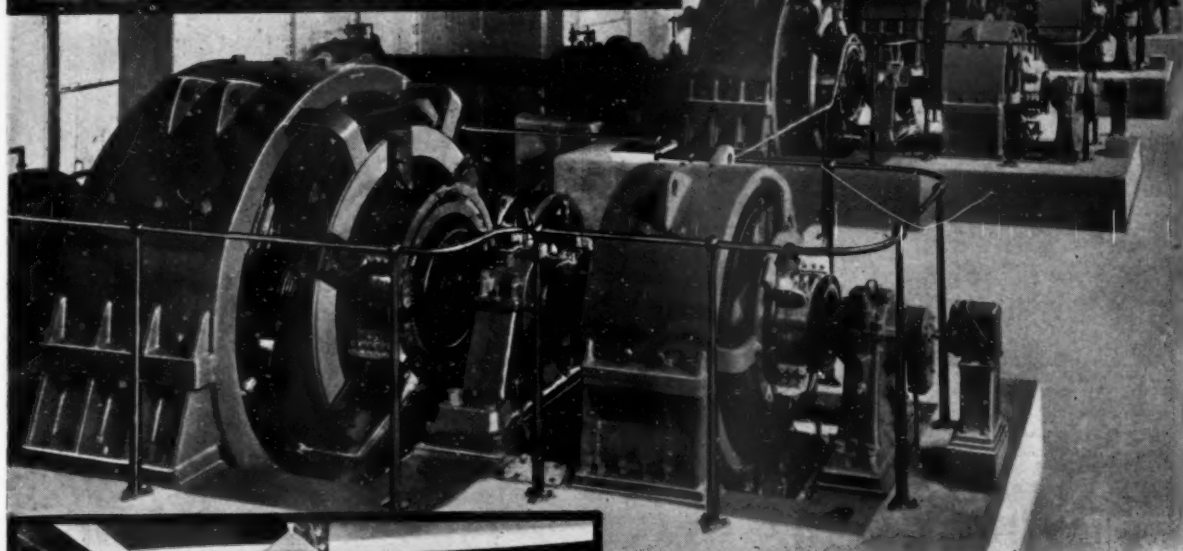
Marshall

Made to the highest standard, our range of products fulfils the requirements of every pouring problem. NOZZLES, STOPPERS, SLEEVES, LADLES and RUNNER BRICKS, etc.

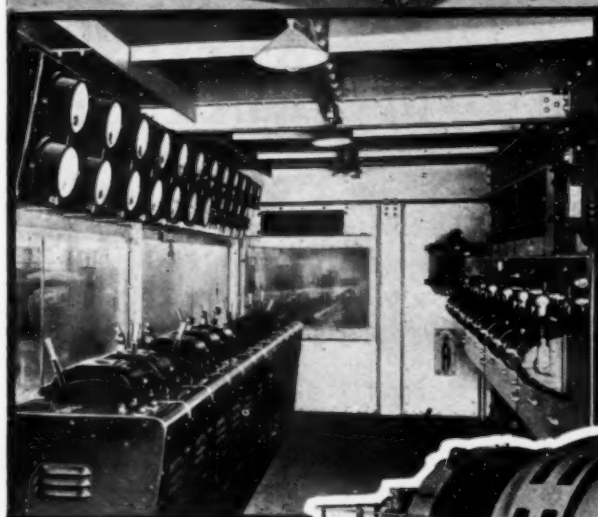
THOMAS MARSHALL & CO. (LOXLEY) LTD., LOXLEY, Nr. SHEFFIELD

'ENGLISH ELECTRIC'

ROLLING MILL EQUIPMENTS

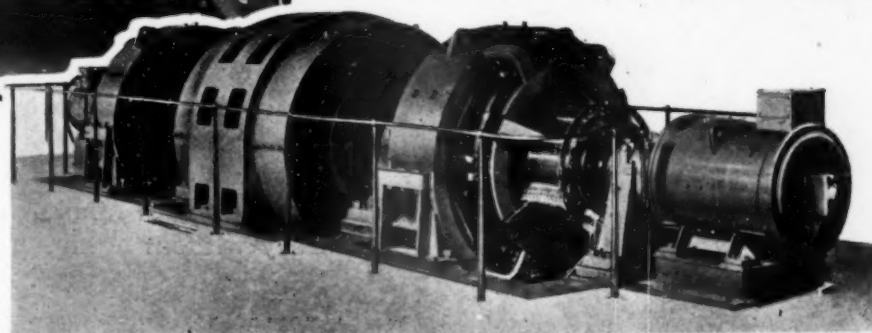


Above : View of motor room showing 750 B.H.P. motors with direct-coupled generators of 120 kW. capacity feeding "edger" motors.



Above : General view of control pulpit.

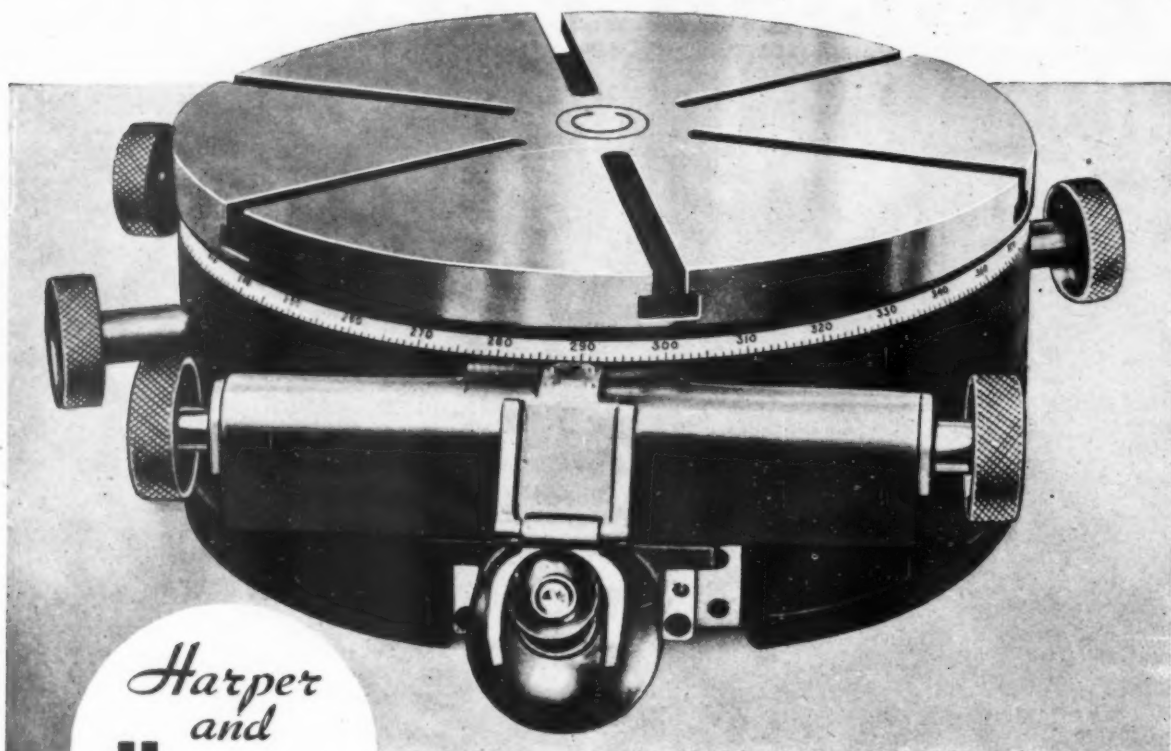
Right : 2,500 kW synchronous motor generator set with direct-coupled exciter.



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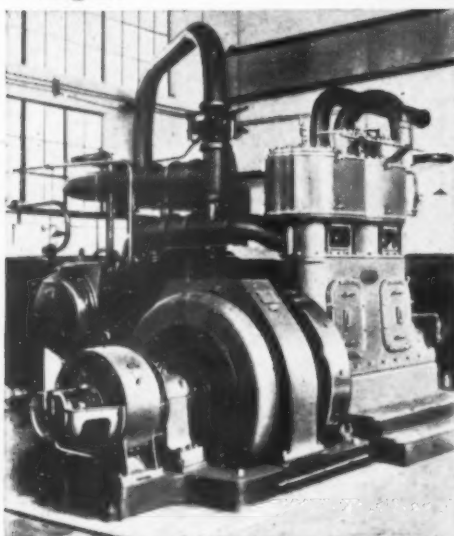
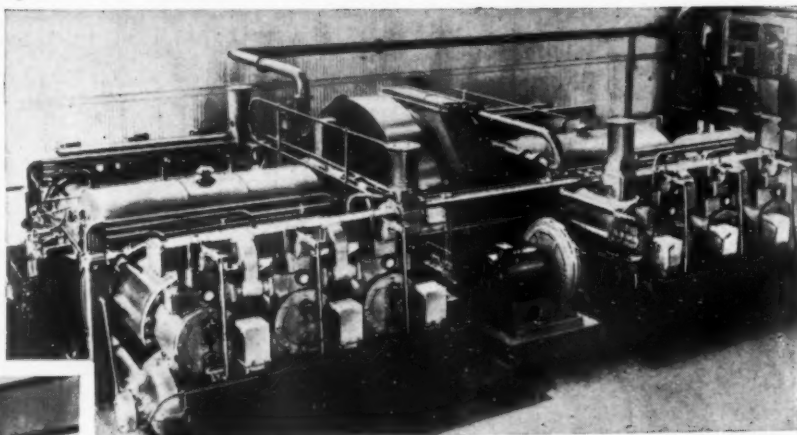


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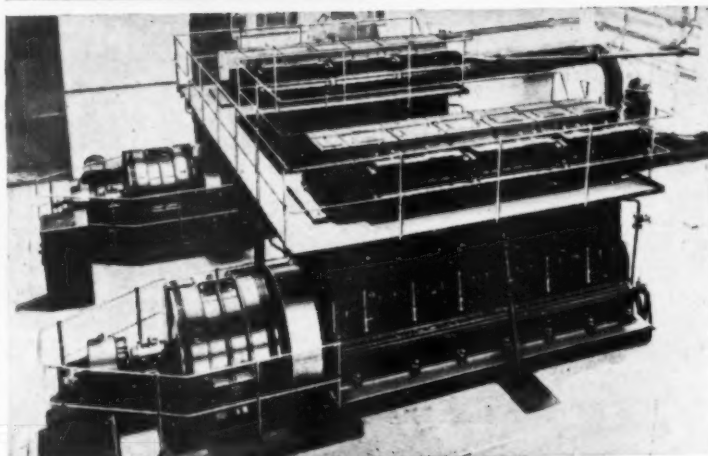
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The illustrations on this page show a few installations of Metrovick Engine Type Generators.

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375 B.Hp. 375 r.p.m. Browett Lindley Steam Engine driving a Metrovick 250 kW 4,000 Volt Alternator at a Chinese Coal Mine.

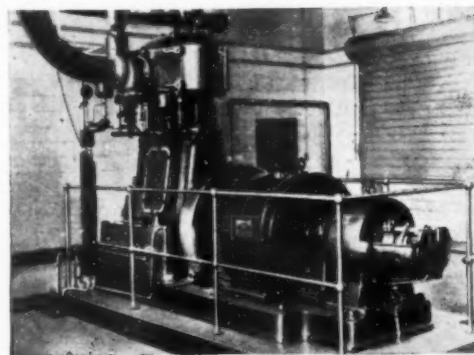


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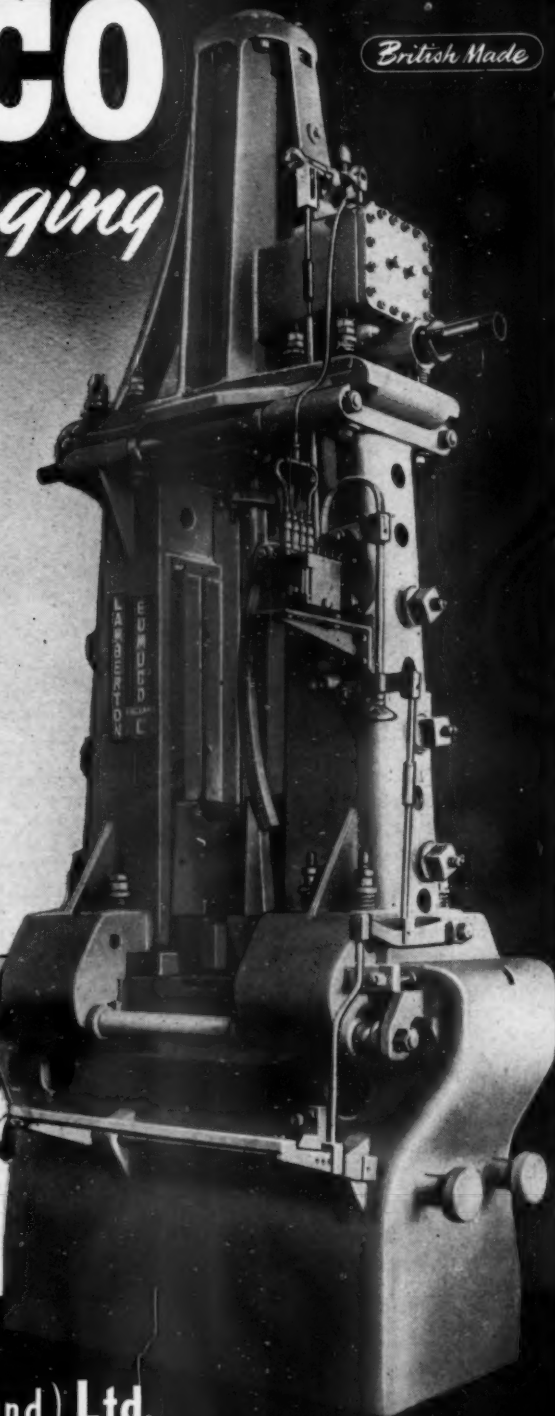
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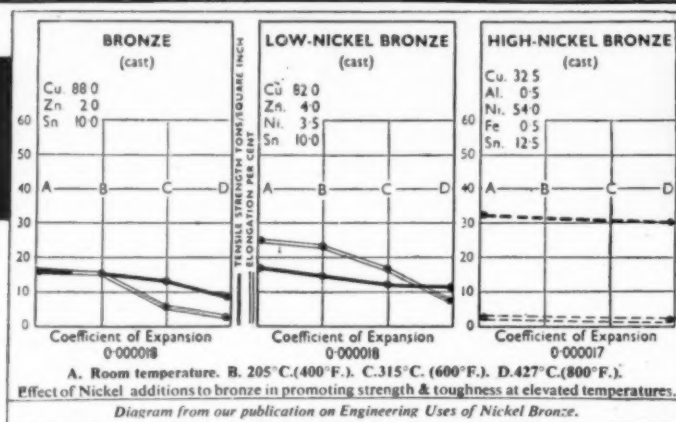
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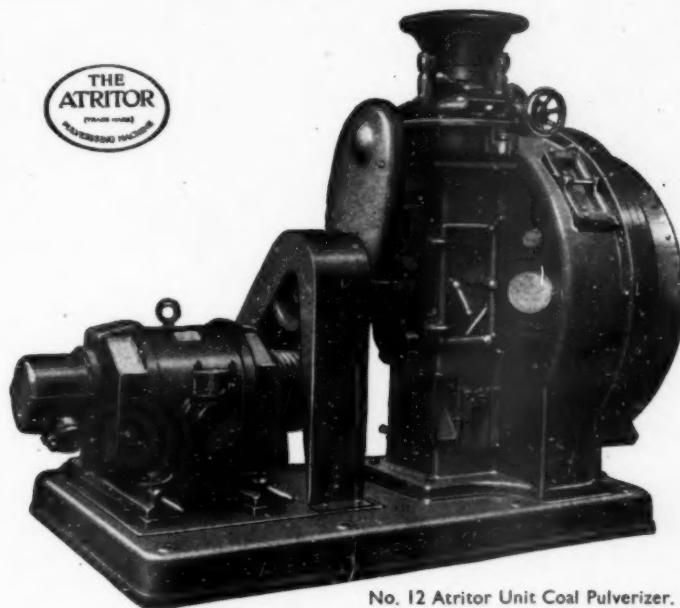
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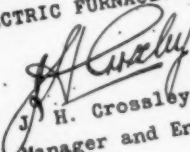
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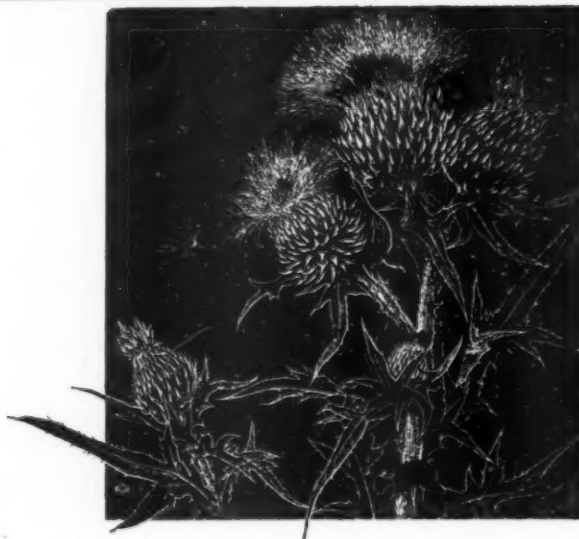
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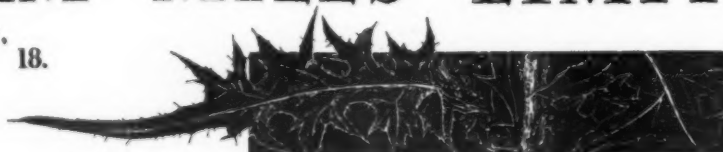
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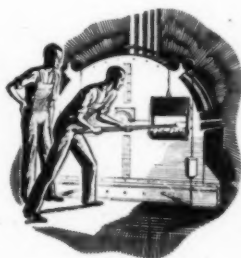
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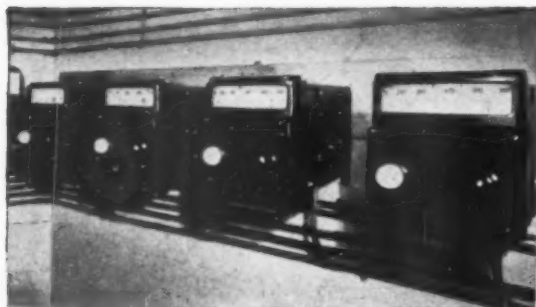
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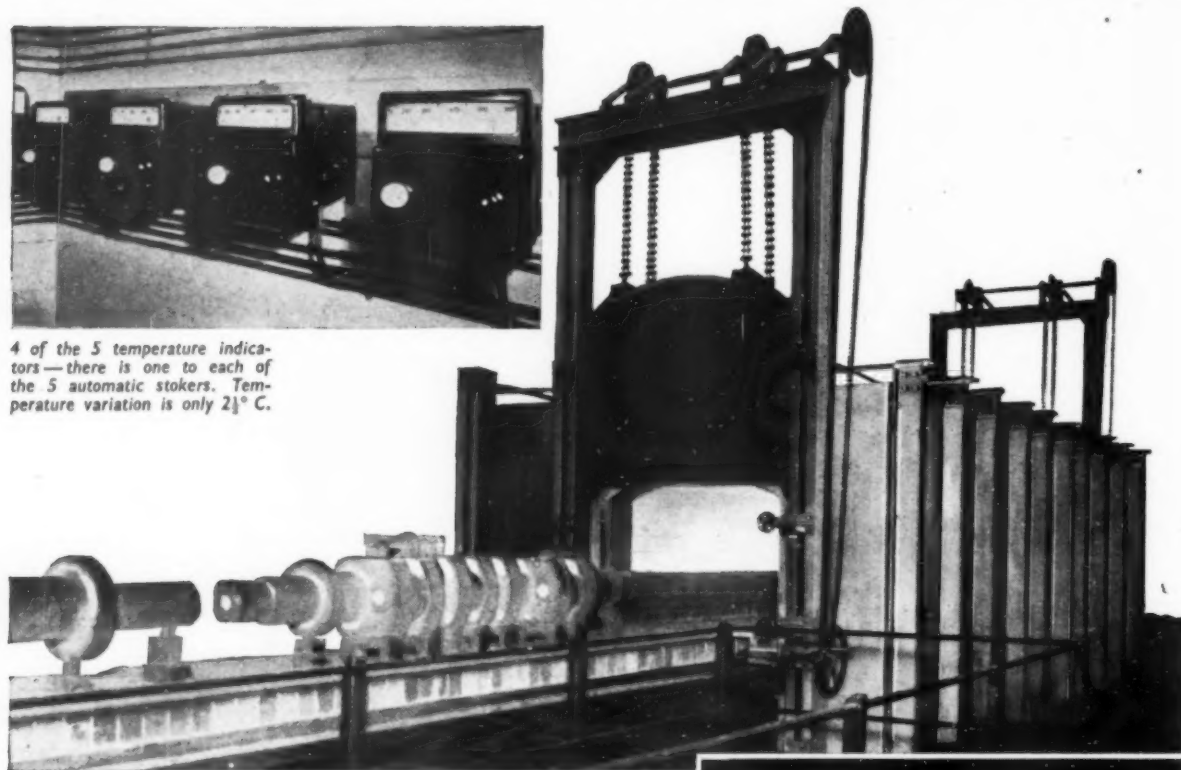
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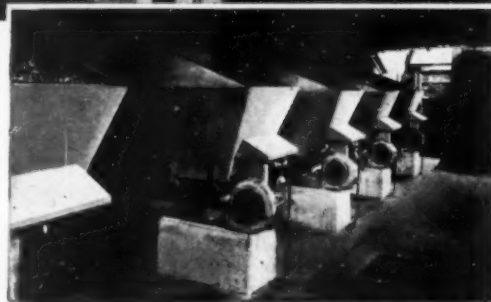
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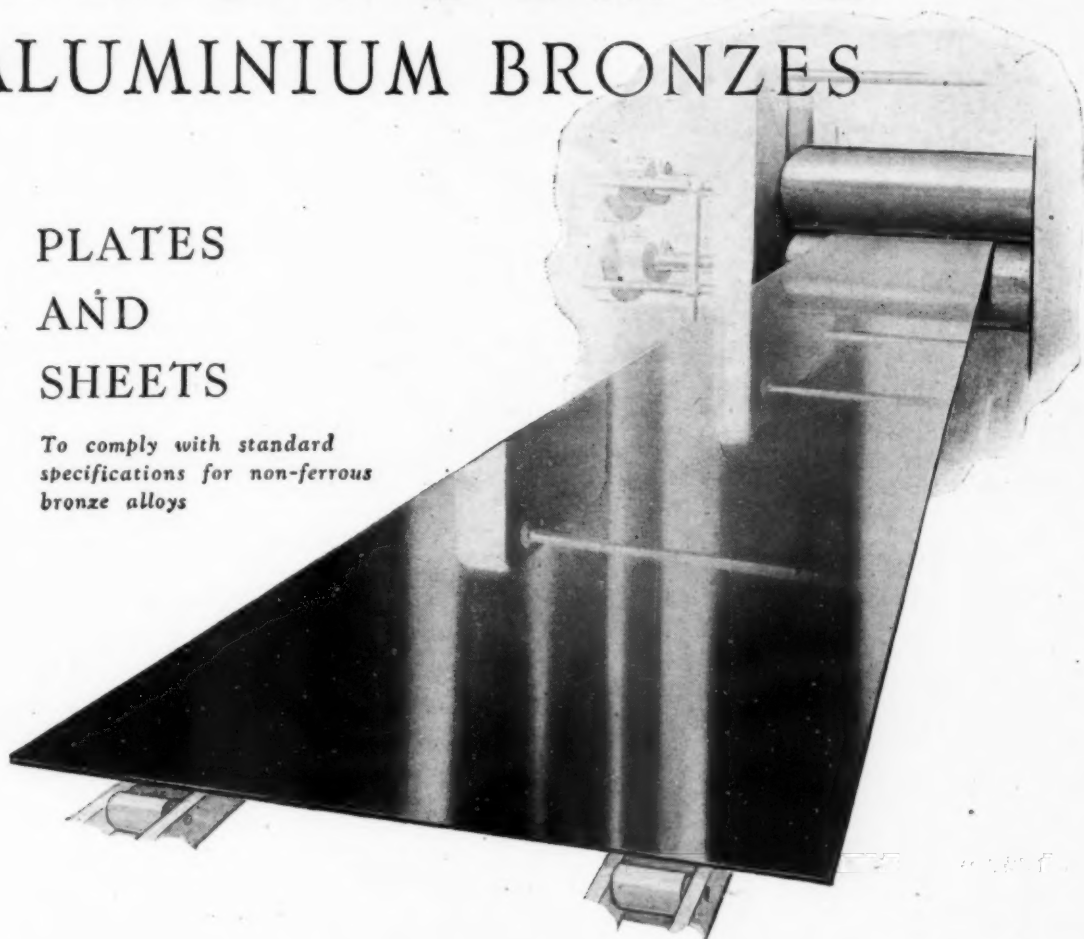
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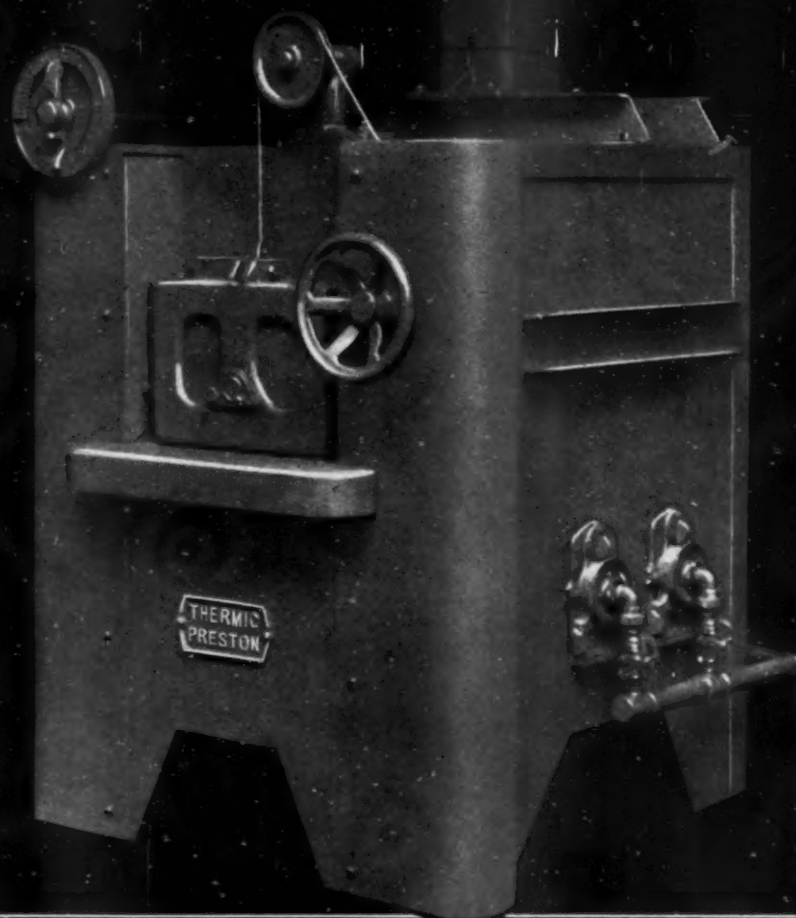


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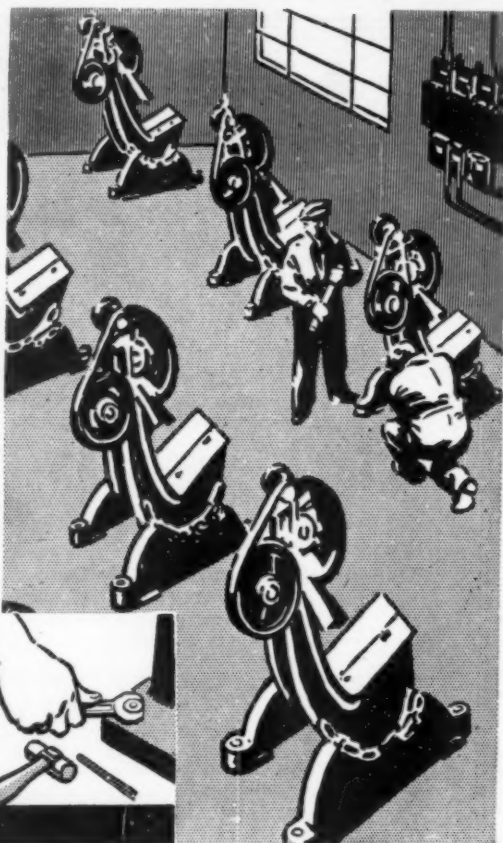
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THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

DECEMBER, 1943

VOL. XXIX. No. 170

Britain . . . 1943

THE majority of those in daily contact with war conditions have been concerned more with duties directed to the speeding of victory, and have not been in a position to take a detached view of what has, so far, been achieved towards this final result. Certainly, since the beginning of this year a great change has been effected in the fortunes of the Allied Nations, but we are inclined to overlook the part played by Britain and inclined to place elsewhere the credit for greatly improved conditions. It is characteristic of the people of this country that they have much to say of failures, but little or nothing to say of successes. It seems appropriate, therefore, to give some impressions of Mr. Vernon Smith, general manager of the Shell Company of Australia, Ltd., concerning Britain and its people, after spending three months in the Homeland.

It is of all-absorbing interest, in this fourth year of war, to see the people of Britain working as they have never worked before, fighting with intensity, planning with genius, enduring greatly with a smile—and, withal, supremely confident not only in the cause for which they are struggling, but in themselves. However sentimental, it is none the less true that in this war Britain has again found her soul. There is nothing boastful about this confidence, for it is too deeply rooted to need surface trimming. Moreover, people who have endured great suffering, and come out of great tribulation, may acquire poise and serenity—but never boastfulness. This would account for Britain's relatively poor showing at national propaganda.

For a year Britain fought alone, and during that year—one of the supreme years in history—she saved the world from worse than tyranny, from slavery, and from death. That, surely, is an achievement amongst the highest flights of heroism, and as the years unfold it will rank as an event as miraculous as the turning back of the Moors from their conquest of Europe, or the routing of the mass invasion of the seemingly all-powerful Mongol hordes, centuries ago, on the plains of Châlons-sur-Marne; it is one of the few decisive turning points in world history. And yet, whilst the fight is still unfinished and many, as in 1918, are feeling tired, outside critics complain of the unsatisfactory nature of Britain's propaganda. Had it

not been for her almost super-human endurance these same critics would to-day perforce be silent and their mouths "be stoppt with dust."

It now seems a far cry to the dark days of 1940, when a relatively small number of fighter planes had to meet the full force of the Luftwaffe in their all-out attempt to bomb England into submission. Though hopelessly outnumbered, the British pilots' dash, individual skill, and natural flair for close-quarter fighting ruined the German dream. There have been great improvements since those days in the quality and

numbers of planes, and in the number of trained crews. Since the middle of last year there have been almost continuous heavy raids over the Continent, reducing cumulatively enemy output and potential, and helping to bring about complete industrial dislocation and transportation chaos. The losses in the Royal Air Force personnel have inevitably been very high; they are the sacrifices made by the very flower of Britain's youth. In consequence, enemy raids over Britain are now relatively few.

The British Navy has become proverbial for its silence and for its efficiency. Yet this war has tested it almost to straining point as never before. Its achievements have never been more brilliant. In the early days of the war it drove the Italian navy back to its harbour shelters; it has protected countless convoys across the dark waters of the Atlantic and through the icy passages to Russia; it has waged an unceasing warfare on enemy submarines, sinking, up to date, a far larger number than were sunk in the last war; and throughout, as mere routine, it has defended Britain from invasion by sea. A band of men—worthy companions of the far more publicised sea-dogs of Elizabethan fame.

And the Merchant Navy—what praise can be adequate for it? Many skippers have been torpedoed time and time again, have lost ship after ship, and still continue in new ships, and, what is even more trying, with officers and crew hastily assembled from other ships that have gone under. These men are on duty almost the whole time. They endure nerve-racking experiences on

the high seas, and yet, if they are lucky enough to reach port safely, they may not even have the opportunity to go ashore for any time, since owing to the shortage of ships they must be on their way again with a minimum of delay. Whenever a worker on shore is inclined

May we take this opportunity of extending to all readers, sincere Greetings and best wishes for A Happy Christmastide and a Prosperous New Year.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

to grumble about his hours or his pay, let him think of these men under unrelieved pressure.

The development of the Fighting Services to their maximum efficiency represents only one side of the picture of Britain to-day. The other side, less spectacular, but none the less impressive—in fact, in some ways more wonderful—is the tremendous output of every form of war material. British industry is everywhere geared to a supreme war effort; whether it be in the increasing flow of ever-improving types of fighters or bombers, tanks or guns, battleships or submarines, the production figures are staggering, and would in themselves do credit to a nation of 45 millions, even if only a small proportion had been available for service in the field. And the material that is being turned out is of the finest British workmanship—still noted throughout the world for its skill and finish. This miracle has been

consummated only by the wholesale employment of women, originally unskilled, but now fully trained and in the highest degree efficient. But even allowing for the colossal influx of extremely adaptable female labour, the output and quality of material would have been impossible without the amazing spirit of self-sacrifice and determination shown by the average British worker, for whose titanic efforts no praise can possibly be adequate.

Mr. Smith concludes by saying that never for a moment have the British doubted their ultimate victory: never has a nation done more to deserve success. But, whatever the views of friends from overseas, do not let the success so far achieved blunt our keenness to give of our best. Let us carry out our respective duties, unflinchingly believing that the cumulative effect will hasten the final victory and much must be done before that is accomplished.

Canadian Industrial Output, 1939-1943

THE transformation of Canadian industrial output in four years of war has been almost incredible, and it is still too little known. Only those who are actually engaged in the general conduct of the war have any real idea of its magnitude; even many actively at work in one phase or another of business enterprise have only a partial conception of the developments that have taken place. Each individual has been too engrossed in his or her own share of furthering the war effort to have time to view the picture as a whole. For obvious reasons of security the details cannot be told, but enough indications are released from time to time to permit the broad outlines of the picture to be sketched.

The Canadian industrial development has taken three main courses during the period of the war; diversion of peacetime products to wartime uses, as in the case of the automobile; growth of industries new to Canada, like machine tool and optical glass production; and the utilisation of Canadian inventiveness in the output of entirely new materials, according to the *Bulletin* of the Royal Bank of Canada.

The Canadian mining industry has also expanded rapidly with output in August of this year at a rate three and one-third times that in the standard period 1935-39. At the present time, Canada is the greatest base-metal exporting country in the world, and in 1943 its output will attain the highest level in history. Factors leading to this record have included the expansion of the aluminium industry, the development of a Canadian process for the production of magnesium, the revival of old mines, the expansion of existing properties, and exploitation of marginal and sub-marginal deposits. Canadian aluminium production is now more than six times that in 1939, being greater than the total production of the rest of the world in that year, and it is supplying about 40% of the war requirements of the United Nations. Canada produces 95% of the nickel, 20% of the zinc, 12½% of the copper, 15% of the lead, 75% of the asbestos, and 20% of the mercury.

On the borderline between old and new industries is the actual manufacture of munitions of war, including guns, ammunition and explosives of all kinds. Although

it cannot be said that these represent a direct diversion of peacetime production to wartime uses, they do represent the utilisation for war purposes of materials ordinarily produced for peacetime uses. Iron and steel, as well as the base metals mentioned above, are used for the production of the guns and munitions. Production of certain types of weapons had been prepared for in Canada shortly before the war broke out, but she does not normally in peacetime maintain an ordnance industry. Recently, however, her largest ordnance manufacturer delivered its 100,000th Bren gun and has delivered more than 50,000 anti-tank rifles and 33,000 aircraft machine guns. She is also producing bomb throwers, trench mortars and Sten guns. Other varieties of Canadian manufacture include 25-pounder field pieces, Bofors, and 3.7 in. anti-aircraft guns, 6-pounder tank and anti-tank guns. These are manufactured complete with mobile mountings, spare barrels, and spare parts. Naval guns of a number of varieties are also produced.

Shipbuilding may also be classed as one of the industries intermediate between old and new. The restoration of this industry to high quantity production has been one of the features of Canada's industrial expansion during this war. When the 200th Canadian cargo ship was launched in August, there had been built within two years in Canada a fleet of freighters equal to 10% of the total tonnage of Great Britain at the beginning of the war. Besides merchant vessels, Canada has produced frigates, corvettes, minesweepers, and patrol vessels, and on September 18 the first Canadian-built destroyer of the Tribal class was launched. On the same day eleven other ships, including two frigates, a corvette, a minesweeper, a naval tanker, two 10,000 ton merchant ships and a Fairmile patrol boat and three tugs were launched.

Only a few of the more important contributions of Canadian industries have been mentioned here, sufficient has been written however, to indicate that Canada is doing a tremendous amount in this war, but just as only those actually engaged in the general conduct of the war have any real idea of the magnitude of her contributions in the past, so they are the only persons who know what Canada's need may be in the future.

Natural Mineral Amalgams

By Douglas Rennie Hudson, B.Sc., Ph.D.

(Lecturer in Metallurgy, Heriot-Watt College, Edinburgh).

"Le mercure, qui paraît jouer un rôle si singulier dans la nature, par sa liquidité habituelle, n'est réellement qu'un métal capable d'entrer en fusion par un tempérament incomparablement plus basse que celle qu'exigent les métaux ordinaires pour se fondre."—HAÛY: *Traité de Minéralogie*, 1822.

ABSTRACT.

The paper reviews critically all available data for the native amalgams of lead, palladium, gold and silver. The latter are the most widely distributed, and often occur in well-formed crystals; two definite species can be recognised:—

1. A mineral containing up to 55% mercury in solid solution in the silver lattice. It is grey or white in colour, sometimes superficially blackened, malleable, ductile, and of variable composition. In the silver-rich specimens regular octahedra and cubes with octahedral truncation are common; with increasing mercury content elongated and dendritic forms predominate, degenerating to grains.

Mohs hardness	2—2½.
Density	12.7—10.5 (varying with composition).
Unit cell	4—4.2A—face-centred cubic.

This species includes *arguerite*, *bordosite*, *kongsbergite*, and the name *mercurial silver* is proposed.

2. An intermetallic compound Ag_3Hg_4 (28.74% Ag), usually with free mercury attached by surface tension, resulting in a brilliant white lustre and greasy touch. Excellent crystals have been reported with rhombo-dodecahedron dominant, truncated on cube and octahedron faces. These show imperfect cleavage on the cubic (and octahedral?) planes, and exhibit conchoidal fracture. They separate cleanly from the gangue—often fluor spar or silica. The mineral is quite brittle, in contrast to the malleability of *mercurial silver*, and emits a "cry" when crushed; after crushing, polycrystalline specimens appear fictitiously soft, and may be moulded.

Mohs hardness	3—3½.
Density	13.5—14.5 (representative value 13.75).
Unit cell	10—10.1A;— γ -brass (imperfect?).

The name *argentat* (after CORDIER, who described crystals from Landsberg) or *landsbergite* is proposed.

The palladium amalgam, *polarite*, is probably cubic, crystallising in fibrous brittle octahedra. It has density, 15.0—16.1; hardness, 3½; and is a definite intermetallic compound, PdHg , in which the mercury is held very tenaciously on heating. *Allopaladium* is a true amalgam with low mercury content, about 5%. *Lehrbachite* is probably PbSe associated with HgSe . It is leaden to black in colour, has a brittle fracture, with density 7.8—7.88.

1.—Historical

ACCORDING to Meller, amalgam is a corruption either from $\mu\lambda\alpha\gamma\mu\alpha$ (malagma) (Livabius, *Alchemia*, Frankfurt, 1597), or from $\mu\epsilon\gamma\mu\alpha$, with the Arabic prefix Al (Ruska). It is derived via late Latin *Amalgama*. Synthetic *Arbor Dianae*, to which the formula Ag_5Hg , has been assigned, was known to the alchemists; it is easily prepared, either from the constituent metals or by chemical displacement of either metal by the other. It is also formed in the *patio* process of extracting silver from a complex sulphide ore. Ogg, in 1897-98,¹ and Reinders, in 1906,² investigated with great care the chemical behaviour of this substance.

The first natural amalgam ever reported was found in the Penning workings in 1660, followed by others in 1689 and 1696 (*Acta Literar. Suec.*, 3, p. 59, 1720).³ Raniey, in 1712, described the existence of native silver, together with mercury in the Juthylls shaft, and this was confirmed in 1754 by Bergenstjerna; *argentum vivum, purum, destillatum, ex cuniculo Juthylls*. It is not impossible that this native (*gediget*) silver was actually a silver-rich amalgam, as reported later by Flight⁴ for a Kongsberg specimen so labelled. In their classic treatises the pioneer mineralogists, Romé de L'Isle

(1783)⁵ and Cronstedt, identified the mineral "*Amalgam*" quite correctly as composed of silver and mercury. The latter's *Mineralogi*, published in Stockholm in 1758, appeared later in two English editions:—

(1) In 1770 (*Translated by G. von Engestrom, revised and corrected by E. M. de Costa*), published by E. and C. Dilly, London.

(2) In 1788 (*Translated by G. von Engestrom, enlarged and improved by J. H. de Magellan*), printed for Charles Dilly, London.

Subsequently, Erdmann's *Mineralogien*⁶ stated that quicksilver, amalgam and cinnabar were found in Sweden. Hisinger's *Mineralogisk Geografi over Sverige*, Stockholm, 1808, attributed native silver, silver amalgam, cinnabar and mercury to the Sala workings.

2.—Occurrence and Nomenclature

When one considers the conditions of formation from magma, the occurrence of native gold, silver and copper is not so surprising; that amalgams should occur native, and often in perfectly formed crystals, is, however, astonishing.

Heyer, in 1790, was the first to publish an analysis,⁷ he found 25% silver and 73.3% mercury in material

from Landsberg, near Zweibrücken (Deux-Ponts), in the Palatinate. Well-developed crystals occur in cavities in soft rock accompanying coal measures. Klaproth, in 1795, found a mercury content of 64% by volatilisation for the same mineral.⁸ L'Abbé Haüy reports this in *Traité de Mineralogie, Paris* (1822), as well as data published by Cordier in 1802.⁹ In those days the only native amalgam known was that of silver, and it was natural that "amalgam" should be adopted as a generic name for all native silver-mercury minerals (for example, Dana, 1904).¹⁰ As discoveries from other districts became known new names were introduced, e.g., *argental*, *mercurial silver*, *kongsbergite* from the Kongsberg mine in Norway, *bordosite* and *arquerite* from Bordos and Arqueros in Chile, (*moschel*)*landsbergite* from Landsberg. It has also been identified at Rosenau (Hungary), Allemont (France), Altai Mountains (Siberia), New Grenada, Almeria and Almaden (Spain), California (U.S.A.). Fig. 1 shows the distribution of native amalgams.

3.—Silver-rich Amalgam

In 1872 Pisani¹¹ suggested a distinction between "amalgam" and *arquerite*, but some confusion seems to have persisted. Very recently (1938) Berman and Harcourt¹² have proposed that *arquerite*, *kongsbergite* and *bordosite* should be regarded as varieties of silver. As Table I clearly shows, the composition of this mineral varies widely. This is quite in accord with the high substituent solubility of mercury in the silver lattice, over 50% by weight according to Day and Mathewson's determination by X-radiology.¹³ Variations from 46.3 to 99.35% mercury have been reported; this wide

range is probably the reason for the difficulty in systematising physical properties, such as density. Another stumbling block is the close association of amalgam and gangue, which renders true density difficult to obtain except by crushing and separation, which may themselves introduce errors. It is quite reasonable that density should vary smoothly with composition between 10.5 and 13.6, values for silver and mercury, respectively, within the solid solution range. Heide²⁹ has shown that this holds for the variation of lattice parameter, from $a = 4.078\text{\AA}$ for silver to $a = 4.176\text{\AA}$ at 50.6% silver in the minerals.

Composition.—Two specimens catalogued as "native silver," from Kongsberg, were found by Flight in 1882 to contain 23% and 7% of mercury on analysis.⁴ As long ago as 1802 the mining engineer, Cordier, showed how silver amalgam could rapidly be distinguished from native silver, but apparently his test did not come into general use. Native amalgam leaves a bright grey metallic streak on copper foil, easily identified under a low-power lens; the difference persists even with increasing silver content, but gradually becomes too small to be sufficient for identification.

Some reservation is necessary in accepting the empirical formulæ proposed, since these are often based on an atomic mass of about 120 for mercury.

South American Minerals.—Domeyko (1841, 1842, 1862)¹⁴ carefully investigated a wide selection of Chilean amalgams, chiefly *mercurial silver*. He adopted a rudimentary classification into "white" and "black" mineral. By separation into fractions based on perfection of crystal habit he obtained remarkably consistent analyses. The author has frequently noted superficial

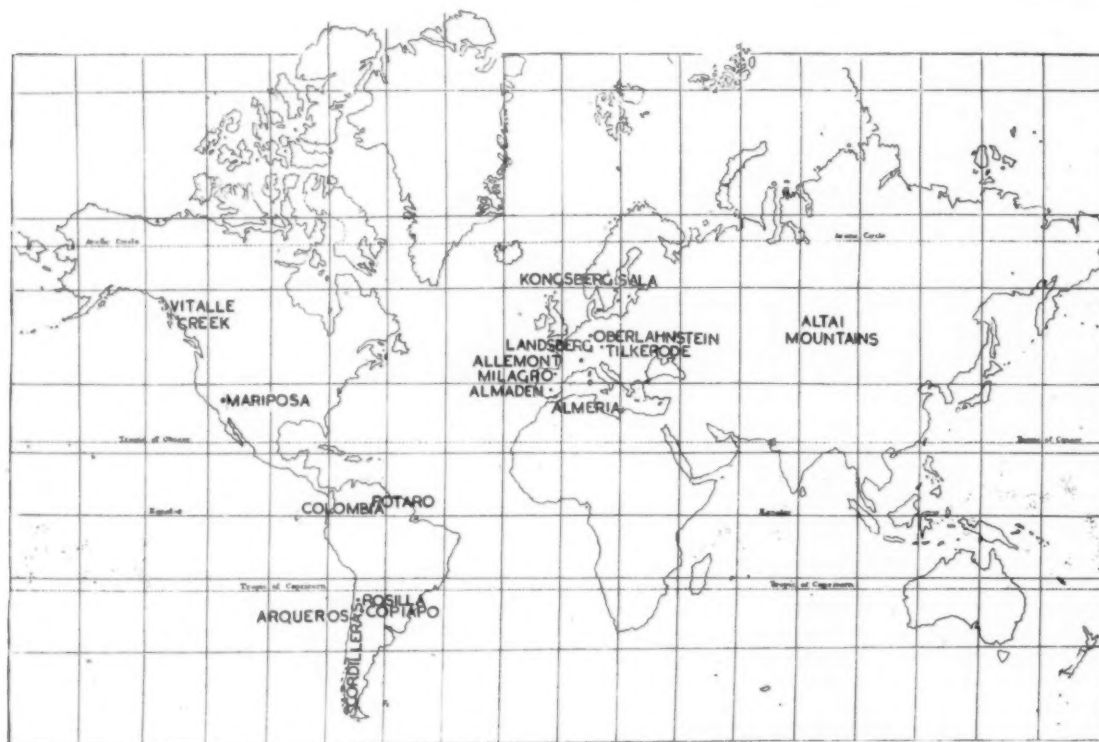


Fig. 1.—Showing the distribution of native amalgams.

TABLE I.
NATIVE SILVER AMALGAM—MERCURIAL SILVER MINERAL.

Locality.	Date.	Composition.			Reported by.	Analyst.	Habit.	Species Proposed.	Density.	Remarks.
		Ag %.	Hg %.	Gangue.						
Arqueros, Chile	1841	86.5	13.5	—	Domeyko	—	Laminar or granular, rarely crystalline. Regular octahedra, elongated or dendritic	—	10.80	Silvery white, malleable, sectile.
Arqueros, Chile	1862	47.6	41.6	—	Domeyko	—	Very fine particles	Various empirical formulae have been calculated, but the mineral is to be regarded as a substitutional Ag-Hg solid solution.	—	"Black" amalgam, irregular masses.
"	"	49.7	43.8	—	"	—	Large grains		—	
"	"	53.3	42.2	—	"	—	Leafy portions		—	
"	"	44.55	39.85	15.6 (including some Ag)	"	—	—		—	
Rosilla, Chile	"	59.4	35.1	5.5	"	—	Porous		—	Malleable "black" amalgam. Analysis on single piece (see Table III).
Cordilleras, Chile	"	64.2	35.8	—	"	—	—		—	
"	"	78.2	20.3	0.9	"	—	Massive—11 kg. block		—	—
Kongsberg, nr. Oslo, Norway.	1872	(95.26) (94.94) (86.3)	4.74 5.06 13.7	—	Pisani	—	Cubes, strongly truncated on octahedral faces		—	—
Kongsberg, nr. Oslo, Norway.	1882	92.45 75.9	7.02 23.07	1.50 0.49	Flight	—	—		—	Catalogued as "native silver"
Oberlahnstein, near Koblenz, Germany.	1882	56.7	43.27	—	Weiss	Pufahl	Gray silvery dendrites		12.703	Silvery.
Santiago, Chile, probably from Arqueros	1888	95.8 53.52 71.94 80.07	3.6 13.18 15.73 (19.95)	— 2.03 3.77 —	Darapsky	—	Three analyses from one single block		—	—
Oberlahnstein, near Koblenz, Germany.	1884	63.13 56.65	36.85 43.27	— 0.08	Sandberger	Zwanziger Sandberger	Tabular and angular or flaky and irregular. Malleable and sectile	Ag ₃ Hg	—	Outer surface dark grey, but interior showed silvery-white colour and bright metallic lustre.
British Columbia . . .	1882	86.15	11.90	0.45	Dana	Hanks	—	—	—	—
Rodaño, near Arqueros, Chile.	1879	(94.4)	5.6	—	Domeyko	Silva	—	—	—	—
Arqueros, Coquimbo, Chile.	1937	99.35	—	—	Heide	—	Compact, rough	a Ag-Hg	Solid solution	a = 4.078A. Between these limits the lattice parameter varies almost linearly with composition. a = 4.176A. B Constituent also nt.
Almeria, Spain	"	92.79	—	—	"	—	Fine plates	"		
Milagro, Navarre, Spain.	"	91.64	—	—	"	—	Fine plates	"		
Oberlahnstein, Germany.	"	51.84	—	—	"	—	Dendritic	"		
Stahlberg, Palatinat.	"	50.60	—	—	"	—	Laminar, polycrystalline	"		

blackening of silver-rich amalgams on exposure to the atmosphere of the laboratory, or even the relatively pure air of a museum case. This is sulphide tarnish, easily removed by gentle rubbing or polishing, to reveal the characteristic bright lustre. Perhaps this phenomenon on a large scale in Nature would explain Domeyko's "black" amalgam. A dark outer layer was also observed by Sandberger (1884)¹⁵ in amalgams from Oberlahnstein, near Koblenz. He drew attention to a remarkable feature of these minerals: with few exceptions foreign metals are small in quantity, and cases of what are virtually chemically pure alloys have been reported. He found no trace of copper, lead or bismuth, while a specimen previously analysed contained only 0.08% copper.

Most of Domeyko's specimens contained either about 46 or 55% of mercury, according to whether well-crystallised or granular material was selected, but one large block from the Cordilleras weighing 25 lb. yielded 79.4% silver and 20.6% mercury, almost free from gangue. Darapsky (1888)¹⁶ reported a variation of silver content from 53.52 to 80.07 in different portions of one of Domeyko's actual specimens deposited at the National Museum at Santiago. In view of the great care which the latter took, one may conjecture that his attention to careful fractionation of the minerals was given in order to overcome this very obstacle—a devotion amply rewarded in the highly concordant values obtained. One cannot but regret that the study was substantially

confined to habit and composition, with but little reference to other physical properties.

Crystal Habit.—From the rather meagre information available, the crystal form of mercurial silver is quite consistent with its existence as a solid solution of mercury atoms in the close-packed cubic lattice of silver. It shows a smooth gradation of properties into those of native silver. According to Pisani (1871), a specimen from Kongsberg, containing 95.26% silver, existed in well-formed cubes of about 1 cm. side, strongly truncated on the octahedral faces.

Individual Chemical Species.—From the variable chemical composition, quite consistent with the extent of the α field in synthesised alloys, the possibility of any definite chemical species seems definitely excluded.

Summarised Properties of Silver-rich Amalgams.—The mineral is white or grey, with metallic or sub-metallic lustre, resembling native silver; the outside layers are sometimes blackened. It is malleable, ductile, sectile, and of variable composition. Regular octahedra, and well-formed cubes with octahedral truncation, are common with high-silver contents; as the mercury content increases, elongated and dendritic forms are common, it becomes granular or massive, and good crystals are exceptional. The mercury content may lie between about 55% and nearly zero, with corresponding variation in Δ between 12.7 and 10.5. Mohs hardness lies between 2 and 2½. The mineral crystallises in the close-packed cubic lattice of silver.

4.—Mercury-rich Silver Amalgams

Data for minerals richer in mercury show at once a greater constancy of composition, greater consistency, comparative absence of gangue contamination, and excellent crystal development. As Table II shows clearly, there is marked concentration of silver percentages in the range 26–30 for minerals from many different parts of the world. The centre of gravity of these is very close to 27.5% silver. Observers agree

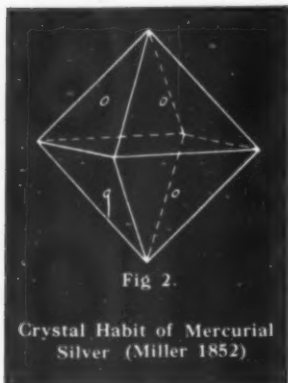


Fig. 2.

Crystal Habit of Mercurial Silver (Miller 1852)

almost unanimously in reporting free mercury, the final thin film adheres tenaciously to the crystals owing to its high surface tension. Gonyer,¹² to overcome this, has used the ingenious device of crushing the crystal and centrifuging the fragments before analysis.

Composition.—A surface in contact with free mercury will quite obviously have the composition of the mercury-rich limit of the solid phase on the equilibrium diagram richest in mercury. Murphy and Preston¹⁷ place this at about 29½%; Stenbeck,¹⁸ from radiological data, found 26%, and Troiano¹⁹ > 25%. By separation of the solid phase under great pressure Hudson²⁰ has obtained coherent solids of composition 27.43 and 27.72% silver, for a specimen that has stood three years in contact with excess mercury. This agrees well with the 27.4% of Dumas²¹ reported long ago, after 17 years' contact. De Right²² (1933) also obtained a composition very nearly Ag_3Hg_4 (28.74%).

If equilibrium has been attained (and where better should this occur than in age-long contact in a cavity within the earth's crust?) the whole body of the crystal, and not merely the surface, will be of the above-mentioned limiting composition. Physical expectations are fulfilled, and the mineral analysis of 27.5% corresponds excellently with the above-determined limits in synthetic amalgams.

According to Preston¹⁷ the range of composition of the artificial γ -phase, to which this mineral corresponds, is only about 1% silver; it is probably this fact, together with the excellent conditions of crystallisation, which accounts for the great perfection of form attained. They, usually separate very cleanly from the gangue.

Species.—Berman and Harcourt¹² have formally proposed the name *moschellandsbergite*. The author proposes that Cordier's original *argental* (1802) should be adopted, but if identification with the original place of discovery is considered a *sine qua non*, he would prefer *landsbergite* on grounds of euphony and sufficiency. Considered as a chemical compound its composition corresponds closely to Ag_3Hg_4 , long known in artificial amalgam as *Arbor Dianae*.

Crystal Habit.—Well-formed crystals are no rarity in this mineral. Cordier,⁹ in 1802, quoted the rhombo-dodecahedron as the fundamental form:—

- (1) With angles at 120°;
- (2) Truncated with faces at 135°;
- (3) Truncated with facets at 150°;
- (4) Truncated with 24 facets at 153° 28'; and 48 facets at 160° 53', the primitive form having angles at 125° 15', giving 122 faces in all.

Flink also found the rhombo-dodecahedron, or the nearest ikositetrahedron, with bounding planes 110, 211, 100, 310, and 321 to be dominant forms.

In Fig. 3, diagrams of the crystal habit of this mineral from the atlases of Häuy, Presl, Maumann, Levy, and the dissertation of Weisbach (*Heidelberg dissertation, Freiberg, 1858*) are shown. With the possible exception of No. 16, all appear to be cubic.

Goldschmidt's²³ analysis of Landsberg crystals in 1913 as Isometric— $\text{I-hexoctahedral}-4/m\bar{3}2/m$ was confirmed by Berman and Harcourt. They found the habit to be dominantly dodecahedral, frequently modified by 001 and 112, a development morphologically consistent with the space-group, according to the rules given by Donnay and Harker.²³ The bounding planes are 001, 013, 012, 011, 112, 111, 122, and 123.

Space Lattice.—Data for the synthetic amalgams are relatively plentiful, but not all concordant. There is general agreement on a body centred cubic cell of 10.0–10.1 Å side. Stenbeck¹⁸ and Westgren¹⁷ believe the structure to be that of γ -brass, i.e. $(\text{Ag}_3\text{Hg}_4)_n$, 25.14% silver, with 52 atoms. Preston expressed very guardedly a preference for an imperfect structure with 46 atoms.* Berman and Harcourt¹², however, prefer a cell containing 50 atoms, and propose $(\text{Ag}_3\text{Hg}_4)_{10}$ for the 10 Å cube. This composition is equivalent to 26.4% silver, which accords better with experience, but not so well as Ag_3Hg_4 (28.74%) in view of the tenacious adhesion of the free mercury. These authors suggest $\text{Im } \bar{3}m$ for the space-group in natural amalgam. Weryha's conclusion²⁴ that the unit cell in *Arbor Dianae* is $(\text{Ag}_3\text{Hg}_4)_4$ in space group O_h^2 would be very difficult to reconcile with the above X-radiological results; the tale of 28 atoms in the above 10 Å cubic unit cell being quite incompatible with the observed density. This investigator, however, obtained identical values for material synthesised from the two metals, and for the crystalline amalgam resulting from Reinders' reaction² between metallic mercury and a solution of silver nitrate. Two chemical compositions, 27.05 and 28.39% silver, are quoted, and material obtained from silver and mercury directly had the same lattice structure.

Density.—Reported values of Δ are not so numerous as one might wish. Häuy's *Traité de Minéralogie* (1822) mentions 14.119 without quoting a source. Cordier⁹ found 14.192 (27.5% silver), compared with 14.57 and 14.26 found by Flink²⁵ (1910). The latter values were obtained by weighing crystals of a fraction of a gramme in benzol, and a large experimental error might be anticipated. Probably the best of the older values are those of Sjögren,²⁷ 13.71 and 11.56 for specimens containing 26.48 and 27.25% silver. The latter contained about 9% gangue, and if allowance were made for this the resulting value would be higher. Heide (1937)²⁸ found 13.78 \pm 0.04 at 27.13% silver, and Berman and Harcourt¹² 13.48 at 27.04%. For synthetic amalgam at the phase boundary, Hudson²⁰ has obtained 13.661 and 13.570 at 27.43 and 27.72%, respectively.

* i.e., $(\text{Ag}_{10}\text{Hg}_{13})_2$.

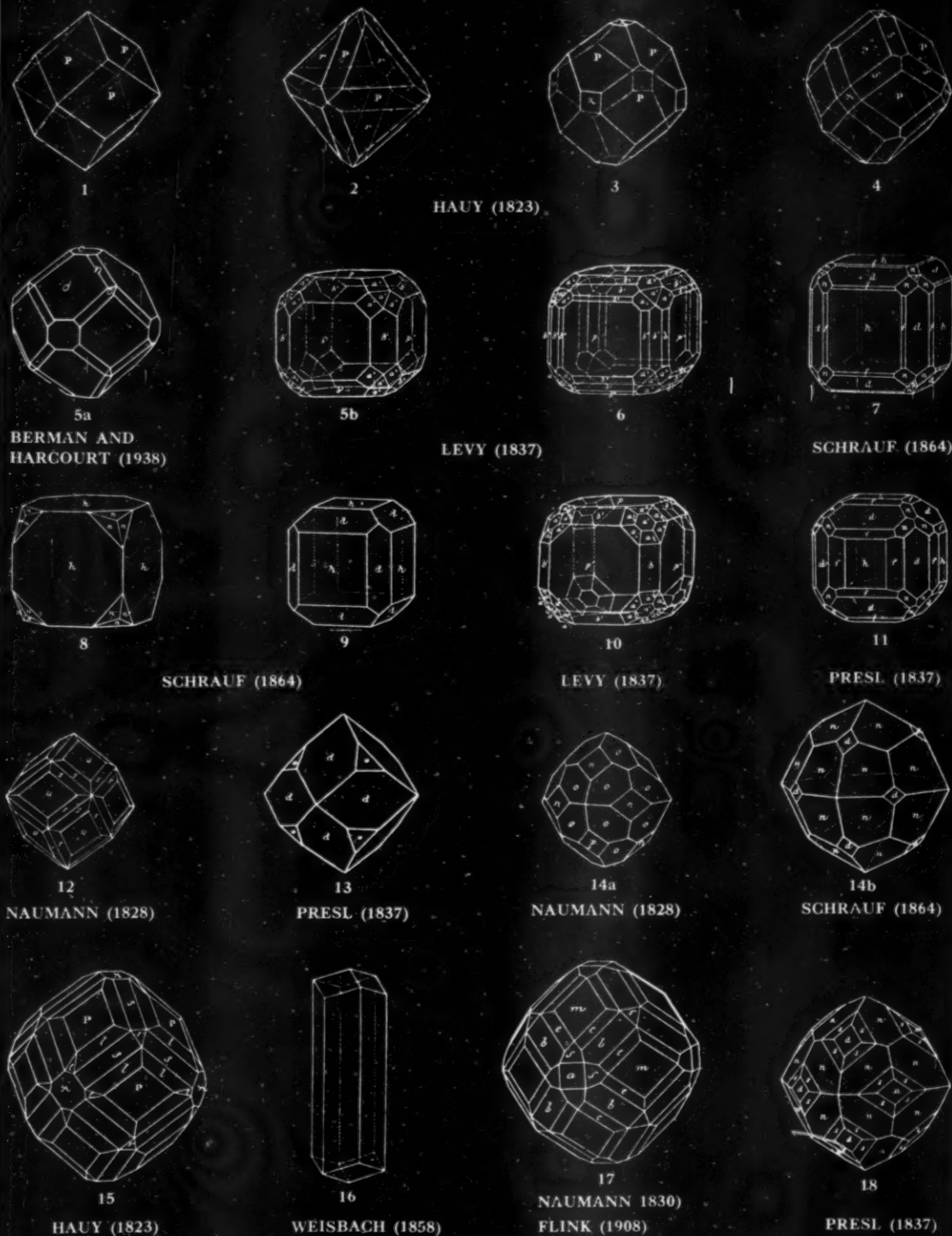
Fig. 3. Showing the Crystal Habit reported for *Landsbergite*

TABLE II.
NATIVE SILVER AMALGAMS—ARGENTAL MINERAL.

Locality.	Date.	Ag %.	Hg %.	Gangue.	Reported by.	Analyst.	Habit.	Species Proposed.	Density. Calcul'd.	Observed.	Remarks.
Landsberg, Palatinate	1790	25.0	73.3	—	Heyer	—	—	—	—	—	—
	1802	27.5	72.5	—	Cordier	—	Threads, leaves or entrapped crystals	—	—	14.192	Dull silver lustre, conchoidal fracture. Quoted by Sjögren.
	1875	26.47	—	—	Rammelsberg	—	—	Ag ₅ Hg ₃	—	—	—
Sala, Sweden	1900	26.48	73.44	—	Sjögren	Maurelius	Crystalline	Ag ₅ Hg ₃	—	13.71	—
	"	27.25	63.86	—	"	"	"	Ag ₅ Hg ₃	—	11.56	—
	"	(29.91)	70.09	—	"	"	"	—	—	—	—
Sala, Sweden Landsberg, Palatinate	1937	29.98	—	—	Heide	—	Compact Compact Loose crystals	Ag ₅ Hg ₃ Ag ₅ Hg ₃ Ag ₅ Hg ₃	—	—	—
	"	28.44	—	—	"	—	γ-brass lattice structure	—	—	—	—
	"	27.13	—	—	"	—	—	—	—	13.78 ±0.04	a = 10.015 ± 0.003A.
	1938	27.04	72.94	—	Berman and Harcourt Berman and Harcourt	Gonyer	1m 3m	Ag ₅ Hg ₃	13.73	13.48	a = 10.1A, silvery, brittle, with conchoidal fracture.
	1913	—	—	—	Goldschmidt	—	1/m 3/m	—	—	—	—
Sala, Sweden (Peningeskatet).	1908	—	—	—	Flink	—	Rhombo-dodecahedra or the nearest ikositetrahedra	—	—	14.26 14.57	From Sjögren's collection.
Synthesised amalgams	1935	22.8	72.2	Nil	Macy	—	—	—	—	13.572	Enriched in silver by compression.
	"	29.5	70.5	"	"	—	—	—	—	13.503	"
	1942	27.43	72.57	"	Hudson	—	—	—	—	13.661	"
	"	27.72	72.28	"	"	—	—	—	—	13.37	"
	"	—	—	—	"	—	—	Ag ₅ Hg ₃	13.57	a = 10.0A	—
	"	—	—	—	"	—	—	—	13.17	a = 10.1A	—
	"	—	—	—	"	—	—	Ag ₅ Hg ₃	14.24	a = 10.0A	—
	"	—	—	—	"	—	—	—	17.82	a = 10.1A	—
	1931	29.5	70.5	Nil	Preston	—	a = 10A 1m 3m	Ag ₁₀ Hg ₁₃	—	—	Synthesised
	1935	27.05	—	"	Werayha	—	a = 10A 1m 3m	Ag ₅ Hg ₃	—	—	Reinders' method and synthesis

The former investigators calculated a theoretical density of 13.49 for (Ag₅Hg₃)₁₀ with 50 atoms, and 13.73 for (Ag₅Hg₃)₄ with 52 atoms. On the assumption that $H = 1.66 \times 10^{-24}$ g., the author has computed the following densities.

Species.	% Silver.	Calculated Density.	
		a = 10.0A.	a = 10.1A.
Ag ₅ Hg ₃	26.4	13.57	13.17
Ag ₅ Hg ₃	25.14	14.24	13.82

It is clear, on several grounds, that the γ-brass structure (Ag₅Hg₃)₄ does not come within the range of stability of the γ constituent in this system (Hudson, 1943)²⁰ but this is not unique. Bradley²⁸ and Stockdale²⁸ have both established that the θ-phase in the copper-aluminium system definitely does not include the

composition CuAl₃, although its lattice structure is typical of an intermetallic compound of this composition.

Summarised Properties of Argental.—The mineral is usually silvery white with excellent metallic lustre owing to the film of liquid mercury on its surface, which also renders it greasy to touch. It often exists in perfect crystals, with rhombo-dodecahedron dominant; the faces 110, 211, 100, 310, 321, 210, 111, 221 have been reported. It is distinctly brittle, harder than mercurial silver, with Mohs number 3 to 3½, and leaves a bright silvery trace on the streak-plate and on copper foil. Crystalline specimens crush easily, with a "cry" harsher than that of tin or cadmium, and hence may show a fictitious softness; they can subsequently be moulded between the fingers. The fracture is conchoidal, with imperfect cleavage on the vertical planes. Composition—27.5% silver, usually a clean separation from the gangue (often fluorspar or silica) is possible. The name *argental* (after

TABLE III.
NATIVE SILVER AMALGAMS INTERMEDIATE BETWEEN MERCURIAL SILVER AND ARGENTAL.

Locality.	Date.	Ag %.	Hg %.	Gangue.	Reported by.	Analyst.	Habit.	Species Proposed.	Density. Calcul'd.	Observed.	Remarks.
Landsberg, Palatinate	1790	—	64	—	Klaproth	—	Massive	—	—	—	—
Chile	1862	44.2	51.2	—	Domeyko	—	Granular—small particles	—	—	—	"White" amalgam.
	"	45.0	51.1	—	"	—	—	—	—	—	"
	"	43.4	50.3	—	"	—	—	—	—	—	"
Rosilla, Chile	1875	41.83	51.13	3.10	"	—	Very fine powder (sieved)	—	—	—	A single piece of the same specimen gave 64.2% Ag, 35.8% Hg.
Sala, Sweden	1875	46.3	51.12	3.03	Nordström	—	—	—	—	—	Associated with dolomite, quartz, and blende.
Juthylla, Prinsens and Latorts Workings.	—	—	—	—	—	—	—	—	—	—	—
Landsberg (?)	1875	35.05	—	—	Rammelsberg	—	—	—	—	—	Quoted by Sjögren.

Cordier)⁹ or *landsbergite*, from its initial place of discovery, is proposed for this species. There seems little doubt that the mineral is a definite chemical compound, Ag_5Hg_4 . The density is 13.5–14.5, with 13.75 as a representative value. The crystal lattice is body centred cubic with unit cell 10A, possibly an imperfect γ -brass structure.

5.—Minerals Intermediate between Mercurial Silver and Argential

Table III correlates the minerals which, on basis of chemical composition, cannot be classified either as *mercurial silver* or as *argential*. These are few in number, and may be close to the boundary of the α solid solution (52% mercury). Four of the analyses due to the painstaking Domeyko¹⁴ represent fine powder sieved off after crushing, or selected small particles. This material is not necessarily homogeneous, and might well contain a mercury-rich component.

6.—The Silver-Mercury Diagram

Murphy's diagram¹⁷ (Fig. 4) includes three phases:—

(1) α , a solid solution of mercury atoms in silver containing up to 54% mercury—equivalent to *mercurial silver* in Nature.

(2) β , an intermetallic compound containing about 40% silver with a range of stability of about 2%; Ag_5Hg_4 , or AgHg —not, so far, identified in Nature.

(3) γ , an intermetallic compound containing about 30% silver with narrow range of stability; Ag_3Hg_2 or Ag_5Hg_3 . Its lattice structure is an imperfect γ -brass structure (Ag_5Hg_3), and it is equivalent to *argential*.

There is no mineral amalgam corresponding to β . Heide²⁰ has gone so far as to suggest that this phase does not occur native, certainly only α and γ have so far been reported in minerals. If α and γ occur in contact, the immediate implication is that β is meta-stable. This would necessitate a minor revision of Murphy's diagram, but is consistent with certain other observations on artificial amalgams. However, it is certain that at room temperature β is quite stable enough to yield consistent lattice dimensions in the hands of many investigators. It is of interest to note that γ , which is relatively definite in Nature, shows small but definite discrepancies on X-ray examination of synthesised alloys.

By electron diffraction from amalgamated silver films, Aylmer, Finch and Fordham²⁵ found evidence for the existence of three lattices:—

(1) A face-centred tetragonal lattice with $a = 6.93$, $c = 5.82\text{A}$, $c/a = 0.84$; after slight amalgamation.

(2) A simple cubic lattice with $a = 17.94\text{A}$, on amalgamation by electro-deposition from mercuric nitrate solution.

(3) A face-centred tetragonal lattice with $a = 9.05$, $c = 5.62\text{A}$, $c/a = 0.62$ on chemical displace-

ment of silver from saturated aqueous silver-nitrate solution by mercury.

Although these results are so strongly at variance with those given by metallographic and X-radiological examination, they have been confirmed by Russian investigators²⁷ using the same electron diffraction technique.

7.—Other Amalgams

Gold.—Gold is rarely found combined in Nature, and native specimens frequently contain silver as impurity. As early as the first century A.D. Pliny gave the name *electrum* ($\eta\lambda\epsilon\kappa\tau\omicron\nu$ = Amber) to the pale yellow mineral alloy—*ubicunque quinta argenti portio est, electrum vocatur*.

Native gold amalgam has been reported only from

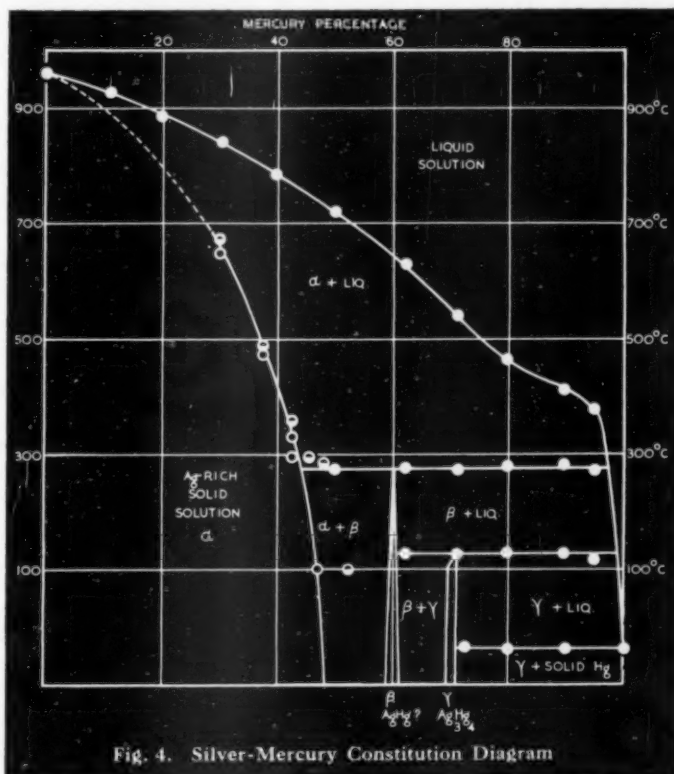


Fig. 4. Silver-Mercury Constitution Diagram

California. Sonnenschein²⁰ in 1848 quoted two analyses made by Schmitz. The latter found the mineral amalgam associated with native and combined mercury in a side valley (*gulch*) 6 to 12 ft. below surface in a formation of shattered green-stone (*breccia* ?), under a cover of clay porphyry. In appearance it resembled quicksilver, apart from a reddish-brown scum; on shaking, lumps formed on the walls of the vessel. After excess fluid had been squeezed out these appeared as acicular yellowish-white crystals; under the microscope they were seen to be quadratic prisms. Although no complete analysis was given, it was explicitly stated that alloying metals other than gold were observed. By vaporisation of the mercury two squeezed specimens were found to contain 39.02 and 41.63% gold.

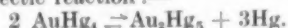
In a platinum ore from Colombia, Schneider³⁸ in 1848 discovered peas of a soft white alloy. On analysis this was found to contain: Gold, 5.0; silver, 38.39; mercury, 57.40.

According to the gold-mercury diagram of Braley and Schneider,³¹ three intermetallic compounds exist:—

(1) Ag₂Hg with 35 atomic % gold, melting at 490° C.

(2) Ag₂Hg₅ with 70 atomic % gold.

(3) AgHg₄ with 80 atomic % gold, formed by the peritectic reaction:—



Palladium.—A palladium amalgam from Tilkerode, in the Harz, was described by Zincken³² as long ago as 1829 under the name *allopalladium*. It occurs in silvery or steel-grey hexagonal tables, crystallising in the rhombohedral system, with perfect basal cleavage and bright lustre.

Spencer,³³ in 1924, pointed out the occurrence of this in British Guiana, but in 1928 retracted this and proposed the name *polarite* for an analogous mineral found in fibrous nuggets in the diamond-bearing sands of the Potaro river. Subject to some specimens being impoverished in mercury by a prior heat-treatment applied in ignorance by the finders, he published the following data:—

Locality.	Pd %.	Hg %.	Density.	Reported by.	Habit.
Potaro River	35.9	64.1	15.82	Harrison	Nuggets with fibrous structure
"	34.8	65.2	15.00	"	"
"	45.6	54.4	15.48	"	"
"	45.1	54.9	15.15	"	"
Knietsur Gorge	—	—	15.00	Bracewell	Conical fragment showed radial aggregation of small crystals.
Synthesised amalgam	36.8	63.2	11.3	Harrison	—

Mercury contents of 54.4 to 65.2% and densities of 13.48 to 16.11 had previously been obtained for the mineral by Harrison. By heating a liquid amalgam of palladium at the boiling point of mercury a solid closely resembling native palladium mercuride and containing 36.8% palladium, with density 14.3, was obtained.

Spencer concluded that *polarite* is probably a definite compound PdHg, crystallising in octahedra, with density 15.0–16.1, hardness 3½, brittle and fibrous, soluble in nitric acid to give a brown solution, and retaining its mercury very tenaciously on heating. He deduced further that Zincken's original *allopalladium* from the Harz was probably cubic in habit. Cizzarz, in 1930,³⁴ carefully examined *polarite* by spectroscopical and microscopical technique. Under the microscope it was found to consist of a regular matrix with anisotropic inclusions, both constituents being apparently palladium amalgams. The Harz *allopalladium* is not identical with these, nor with native cubic palladium. It is a true amalgam with low mercury content below 5%, and associated with platinum, ruthenium, and copper.

Lead.—*Claustalite*, lead selenide PbSe₂, occurs associated with *allopalladium* in the Harz. It contains mercury, platinum and its co-metals except rhodium, and various heavy metal impurities.

Lehrbachite, from Tilkerode and Lehrbach, is variable in composition. Its selenium content at 24.4–27.68% is fairly constant, but a lead content varying from 55.84 to 16.93 and a mercury content varying from 8.33 to 55.52 have been reported. Dana regards the

mineral as PbSe, associated with HgSe. It is massive or granular, with brittle fracture and density 7.8–7.88, leaden to black in colour.

It is a very pleasant privilege to acknowledge the unflinching co-operation of the librarians of the Heriot-Watt College, the University, and the Royal Society, and the facilities granted by Professor Arthur Holmes, F.R.S., of the Geology Department, and Dr. A. M. Cockburn, Curator of the Currie Mineral Collection. Without these the research described in this memoir would have been seriously hampered. The author would much appreciate the loan of any of these minerals which readers have under their control and could make available for investigation—subject to due acknowledgment.

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Bonded Deposits on Economisers

THE problem of boiler plant availability in power stations has become so prominent that a better understanding is essential of the causes of the fouling of heating surfaces by deposits from the products of combustion. To assist a better understanding of the causes investigations have been carried out, the results of which are described by J. R. Rylands and J. R. Jenkinson, in a recent paper submitted for discussion at a Joint Meeting of the Institution of Mechanical Engineers and the Institution of the Electrical Engineers.

Earlier theories based on fused ash particles, sodium sulphate bond or high dewpoints have not satisfactorily accounted for various well-established facts of observation. The latter include the existence of a period of apparent immunity from deposits in a new boiler plant, the characteristic behaviour of the dust from pulverised fuel firing and the peculiar scale-like form of certain hard deposits occurring on economiser and boiler tubes.

Restricting their observations largely to economisers, the authors have found that hard-bonded deposits result from certain chemical reactions between flue dust and sulphuric acid.

Refractories from the User's Viewpoint

By Bernard Thomas, F.Inst.P., F.Inst.F.

It is little more than a decade since refractories were a commodity purchased as the prerogative of a works purchasing department, and the technical staff had no "concern" in the matter other than criticism when the life of any particular material was unduly short. Developments over the last few years, however, have made great strides, particularly in the light of the special reports published by the Iron and Steel Institute Sub-Committee on Refractory Materials. In the present paper, read at a recent meeting of the National Association of Clayworks' Managers, the author considers what an average modern user requires of his refractory materials to withstand conditions prevailing in a small drop-forging plant.

Temperature Considerations

TEMPERATURE is probably one of the first considerations necessary in choosing a refractory brick, followed closely by that of conditions. Knowledge of the actual temperature to which the bricks will be subjected is essential, otherwise an unwise choice might well result in a wall or arch melting away too quickly.

Most bar- or billet-heating furnaces, fired by solid fuel of the hand- or mechanically-fed types using coke or coal, have a temperature at the arch slightly too great for the normal standard-grade firebrick with its 30-35% alumina, and although such may last perhaps from four to six weeks, the substitution of a siliceous grade will often result in 20 to 25 weeks' service.

In qualification of the term "siliceous" instead of silica, it should be explained that the true silica brick, containing 95-96% SiO_2 , so much used in the arch of the open-hearth steelmaking furnaces, owes much of its success to the uniformity of temperature which prevails throughout its life. In a large furnace, however, where only one or two shifts per day are worked, and, worse still, where the furnace may become cold at a weekend, the true silica brick is not too successful owing to its propensity for spalling under sudden heating and cooling conditions. By lowering the silica content to slightly below 90%, such tendency for spalling is largely eliminated, and beyond that the exposed ends of the bricks in the arch glaze over to form a smooth surface which resists temperature up to its refractoriness point at 1,670°C. Incidentally, 89% SiO_2 represents the eutectoid composition of refractoriness values. A typical composition of a siliceous brick is shown in Table I, together with a true silica for purpose of comparison.

If heating is done by oil or gas the intensity of temperature at the arch is rather too much for the siliceous brick, and a higher refractoriness figure is required, being usually met by the employment of the lower grades of aluminous types containing 41-44% of that element. The refractoriness figure of such aluminous bricks is of the order of 1,750°-1,770°C., and three typical compositions are given in Table II.

The same type of brick as listed in Table II withstands very successfully the erosive conditions which prevail where pulverised fuel is used. The grit-laden gases and fuel ash demand a degree of hardness in texture which neither silica, siliceous or common grade bricks are able to provide.

TABLE I.—SILICA AND SILICEOUS TYPE BRICKS.

	Silica,		Siliceous,
Silica	95.52%	..	89.50%
Alumina	1.06%	..	8.10%
Iron oxide	0.85%	..	0.70%
Titanic oxide	0.35%	..	0.70%
Lime	1.92%	..	0.24%
Magnesia	0.09%	..	0.13%
Alkalies	0.56%	..	0.10%
Loss on ignition	0.06%	..	0.02%
Refractoriness	1,720°C.	..	1,670°C.
Porosity	24%	..	26.4%

TABLE II.

	A.		B.		C.
	%		%		%
Silica	53/51	..	51/42	..	51/29
Alumina	42/44	..	42/44	..	42/40
Iron oxide	2/60	..	1/89	..	2/65
Titanic oxide	1/10	..	1/47	..	3/11
Lime	0/40	..	0/41	..	0/18
Magnesia	0/50	..	0/29	..	0/21
Potash	0/01	..	0/62	..	0/63
Soda	Trace	..	0/22	..	0/20
Refractory test ..	1,760°C.	..	1,760°C.	..	1,770°C.

It is well known that silicon-carbide refractories offer superior properties to almost any other material, particularly in application to arch construction. There are two disadvantages which need consideration, however, these being, firstly, their greatly increased weight, which calls either for a more robust construction and, consequently, more expensive one of supporting character, and, secondly, the economic situation.

The green chromous bricks tried out in tentative manner prior to the war were also greatly superior in refractoriness value, and while having the advantage over silica carbide as regards weight, had little or none in respect of cost.

Before leaving the question of temperature, an example of experimentation on the arch of a large muffle-type bar-heating furnace of flat-bottom design, coal-fired each end by mechanical stoker, may be of interest. The overall length of the structure was 23 ft., and it was found that the flames had a habit of cutting through the arch at the point over the brief wall dividing the combustion from the heating chamber. Arches built of standard grade bricks of 30-35% alumina had a life of only six weeks, working 24 hours daily, and six days per week. Siliceous bricks made a vast improvement, the life being extended to 55-60% weeks. Several grades of 41-44% alumina bricks were then tried without any noticeable difference until at last one particular all-mine Scottish type was found at 39% alumina, and

this was the means of increasing the life to 24-27 months. To record an increase in life from six to approximately 110 weeks merely by discrimination in choice of refractories is something which justifies the existence of a technical staff.

Where lower temperatures prevail, such as in the walls of the furnace as already described, neither slag or grit is likely to cause much trouble, and it is usually found that the common grade bricks stand up to the conditions adequately, and, in fact, are in better shape than the arch when time comes to rebuild the structure entirely.

For the completion of records, typical compositions are given in Table III of what are described as standard and common firebricks.

TABLE III.—TYPICAL COMPOSITIONS OF STANDARD STOURBRIDGE FIREBRICKS.

	A, %	B, %	C, %	D, %
Silica	60.52	69.76	58.20	53.80
Alumina	33.81	25.56	34.88	39.21
Iron oxide	2.22	1.79	3.19	2.72
Titanic oxide	1.14	1.00	1.90	1.60
Lime	0.65	0.60	0.57	0.29
Magnesia	0.51	0.38	0.51	0.71
Alkalies	1.15	0.85	0.71	1.35
Ignition loss	—	0.06	0.20	0.21
	100.00	100.00	100.16	99.90

Analyses A and B are the better, or "No. 1 Qualities," while C and D represent a lower-priced grade designated usually as "B" quality.

It will be noted that the iron-oxide averages almost 1% higher in the lower-grade brick, while the other main differences consist of a lower silica and higher alumina content, as compared with the No. 1 quality. It should not be assumed, however, from the typical analyses of these Stourbridge bricks that all high-alumina bricks are to be avoided, as, quite apart from the sillimanite types, some of the best Scottish bricks average 42-44% alumina.

Spalling

Spalling is one of the worst sins to which many refractories are subject, and when it develops ultimate failure is only a matter of brief time, as the jagged ends cannot glaze over to offer self-protection; and, furthermore, the smooth flow of the gases becomes interrupted. Spalling is due largely, of course, to the inability of a brick to withstand thermal expansion and contraction without cracking, and may be caused by cracks already present from the drying and/or firing stages, or by the close and even texture of a hard machine-pressed product.

Manufacturers of refractories usually explain that reasonable care should be employed in slowly heating furnaces from the cold, but this cannot always be observed, especially in cases where operators are on piece-work and turn on blast and fuel supply to the utmost extent in order to attain working temperature at the earliest possible moment.

It may be surprising to state that a cheap hand-made or wire-cut brick may often be superior to one machine-pressed from the same clay, from the viewpoint of spalling, and part of the reason is doubtless due to the rougher surfaces allowing greater freedom of movement under fluctuating thermal conditions. One brick of local manufacture, of which the author has knowledge, and

used to a considerable extent for low-temperature work, resists spalling far better than any other type used, irrespective of price, and the texture is of a nature so coarse as to cause amusement amongst contemporary suppliers. Intermingled in the texture of the brick is a grog up to $\frac{3}{16}$ in. particles, obtained mainly from crushed siliceous bricks of composition as Table I, and this grog is doubtless one of the reasons for its anti-spalling success. It is unfortunate that the clay, in itself, is not of better quality, as otherwise it would be a still more successful commodity than at present.

Hearths

Hand-fired coal-furnace hearths are too low in temperature to give trouble from slagging, and clinker can usually be withdrawn dry with ease. Where mechanical stoking is employed, however, greater temperature is generated by the presence of the retort, and fusion of ash and clinker often occurring, which position is made worse if bar stock is heated above the fuel bed as the drippings of liquified scale adds to the molten mass beneath.

In the early days of the application of mechanical stokers for industrial furnace firing, the hearth bottoms were built up square, which enabled bricks of standard shape to be employed. Developments over the years, however, have led to the use of a shaped bottom to avoid awkward angles and corners into which fuel or clinker may go to build up into a dead mass.

Prior to the war the square-shaped structures were first built of chromes and chrome-spinels for slag resistance, followed by shapes of magnesite composition. In all instances, however, spalling took place to such a serious extent that half-bricks would be removed from the hearth adhering to the ash, slag or clinker. Typical compositions of such types are given in Table IV.

TABLE IV.—TYPICAL COMPOSITIONS OF CHROME AND CHROME-SPINEL BRICKS.

	Chrome, %	Chrome-spinel, %
Magnesia	35%	39%
Chromic oxide	25%	24%
Alumina	17%	16%
Iron oxide	14%	14%
Silica	7%	5%
Refractoriness under load	1,560° C.	1,600° C.
Porosity	19%	22%

Despite the wide range of proprietary brands of the three grades named, none appear able to give satisfaction, although magnesite was the poor best.

Following closely on the trouble described came another difficulty with furnaces having a separate heating chamber, due to slag cutting its way through to the lower level of the combustion chamber and solidifying round the metal feed-worm screw of the stoker, which would soon result in a furnace stoppage through either preventing the fuel feed or actually bending or seizing the screw.

This difficulty at one time was the most serious encountered with forge fires stoked mechanically, and to overcome it the hearths were made bowl-shaped by ramming hard a mixture of magnesite, rubble, peas and cement, and allowing to dry out thoroughly, which resulted in a neutral bottom which resisted very satisfactorily the encroachment of slag and also fusion of ash and clinker.

At that time this was the greatest advance made in hearth bottoms until the commencement of hostilities, and the difficulties in obtaining the magnesite, coming

as it did mainly from Austria, and in some doubt a change was made to the use of dolomite clinker, again in the form of rubble and cement, using 50% of each and ramming down moist in a similar manner to the previous use of the magnesite. Somewhat surprisingly this was a great success, and it was found very soon that the results were superior to those obtainable from the magnesite. Not only was the material resistant to slags, but it did not react with the slag to "build up," as happened to a certain extent with both magnesite and also with chrome and chrome-spinel bricks used previously. Thus, some slight good has come through certain short supplies caused by the war, and not the least interesting point is that even to-day the cost of such basic material is not much more than half the pre-war cost of the imported magnesite.

Somewhat similar trouble was experienced in flat bottom hearths of heating chambers as distinct from those where combustion takes place, particularly in cases where temperatures of 1,300°-1,350° C. are employed. Such temperatures cause the surface of the metal being heated to "wash" off, with the result that the furnace bottom was invariably wet with a thin slag. Where the heated metal pieces were subsequently required for pressings, as distinct from drop forgings or stampings, such wet slag on the surface became pressed in and, instead of a smooth, clean, oxidised finish being available subsequently, a scarred or "scabby" surface was presented. Such surfaces were made worse in appearance if grinding or polishing was required at a later stage.

In this connection the various chrome, chrome-spinel and magnesite bricks available were tried, as also were sillimanite and various hard-burnt bricks of higher refractoriness which were calculated to resist slag or fusion. None but the neutral and basic types had any success, and even these latter had a habit of "building up" in convex fashion, and after a time the irregularities caused by such development would be inevitably knocked by incoming cold work requiring to be heated and result in spalling, which would take away not only the built-up portion but probably $\frac{1}{2}$ in. of the other material in addition. The ultimate result was, therefore, that in approximately two to three weeks of service the hearth was simply a mass of broken pieces of brick. Although the period of life was two to three times that obtainable from the ordinary types it was not satisfactory, and after a period where a tamped bottom of magnesite was used with fair success, bricks of stabilised dolomite were employed and resulted in considerable success, the average life being eight to ten weeks as compared with two to three weeks on the neutral and basic types, and one week with aluminous grades. The analysis of the dolomite bricks and clinker are given in Table V.

TABLE V.

		Dolomite Brick, Dolomite Clinker.	
		%	%
Silica	SiO ₂	15.32	6.3
Titanium oxide ..	TiO ₂	0.14	—
Alumina	Al ₂ O ₃	1.02	1.6
Ferric oxide	Fe ₂ O ₃	3.62	1.6
Lime	CaO	37.80	48.1
Magnesia	MgO	40.68	32.9
Chromic oxide ..	Cr ₂ O ₃	—	8.7
Loss on ignition ..	—	—	—
Steam hydration index	—	2.87	3.8

One disadvantage of the dolomite material is the tendency for its lime content to hydrate on storage if

conditions are unsuitable and it is necessary to stabilise by the addition of some mineral, the most successful of which is believed to be chromium oxide, and the composition of a clinker is given in the table which contains this stabilising compound.

General Construction

From the foregoing remarks it may be gathered that it would be considered a bad policy to use the same type refractory throughout the construction of any single furnace. To summarise the position, therefore, the user should study, firstly, the hearth conditions of his combustion chamber, which may vary according to the nature of fuel employed; secondly, the question of temperature, as to whether there is any likelihood of slag either through melting of scale metal or fusion of ash and clinker; and thirdly, whether the heating of the steel takes place directly in the combustion, or in a chamber separately disposed. Each of these various conditions should be met by a grade of refractory most suited to withstand the conditions.

With the walls it is usually found in most cases that these have the least service, and bricks may be withdrawn scarcely touched at the end of the furnace life. One precaution only would appear worthy of mention, and that is that better service is obtainable by building a 9-in. wall of "headers" than is possible by building the same thickness wall with the normal construction of two layers, $4\frac{1}{2}$ in. thick, interbonded as building proceeds. The superiority lies in the greater potential resistance to spalling, as the end of any brick presented to the source of heat is at all times not greater than $4\frac{1}{2}$ in. plus the thickness of the brick, either $2\frac{1}{2}$ in. or 3 in., as the case may be, whereas in the more normal construction the exposure might well be 9 in. \times $4\frac{1}{2}$ in. \times $2\frac{1}{2}$ in. or 3 in. thickness accordingly; this point is not always appreciated.

The arch construction depends, firstly, on temperature conditions. The lowest priced brick of sufficiently high refractoriness value is obviously the correct one to employ, e.g., if only a low temperature of 1,100°-1,200° C. is necessary the ordinary 30-34% alumina bricks will be perfectly satisfactory, but if there is any tendency for these to drip the next recourse would be a siliceous grade as described previously at 88-89% silica, and in most instances these will be found even more satisfactory than the more popular grades at slightly higher alumina content of 40-44% of that compound. If even these are found unable to withstand the temperatures necessary the next resort would be to a sillimanite type of 80-90% P.B. sillimanite, which offers a refractoriness figure of around 1,800° C., which is usually ample for the most stringent requirements.

In the unlikely event of all the foregoing types failing in the arch, there still remains silicon-carbide, which would be satisfactory to approximately 1,825° C.

Shape

Whilst shape is important, it should not be obtained at the cost of a reduction in spalling resistance properties, as may sometimes occur, but it is obvious that a good shape is desirable to obtain neat joints, and it becomes therefore a matter of keen discrimination to obtain such where other properties in addition have to be observed.

In the building of arches some thought should be given to the radius of the finished structure, and the correct

taper of bullhead or end arch should be employed which will "throw" the correct curve without the insertion, at intervals, of a square to adjust as might otherwise be necessary. A square offers no key, and accordingly constitutes an area of reduced strength, if not actually weakness, and as any furnace structure is no stronger than its weakest point this should be borne in mind and a generous selection of tapers kept in stock.

Jointing

The thinnest possible joint is naturally the most satisfactory, and the writer has knowledge of one Black Country furnace builder whose joints are so neat as to be almost indiscernible, and on completion of building a structure the man produces a carpenter's pencil with a thick lead and actually draws the joints so that it may be seen where they exist; this is a true statement of fact.

Whilst it is desirable that the bonding clay should at all times be of the same clay from which the bricks being used were manufactured this, unfortunately, cannot always be put into practice; it would lead to a wide variety of clays being in existence with the inevitable risk of mixture. As an alternative, the best possible general clay should be employed containing as much grog as it can reasonably hold, and still form a bonding medium, and whilst for rough work the grog could be ground to approximately 40-mesh, for high-temperature requirements a mesh of over 100 would naturally give infinitely superior results. Cases have been heard where a mesh of 200 has been employed, but this may be taking things a little too far for normal purposes. The grog, of course, should consist of scrap firebricks, those of siliceous nature giving better results than others having a lower content of that oxide.

Before leaving the question of jointing, it may be added that over a number of years' experience it has been found more satisfactory to mix approximately 1 ton of fireclay in readiness for use some days or even weeks ahead, rather than mix immediately as used. Various people will doubtless have different ideas on this particular point, but it is a fact that joints appear to run much smoother by adopting this system.

Jointing or Patching Cements

There is on the market at the present time a wide range of jointing cements which are liked by many users for the facility they offer in the way of patching to make a furnace last just that little while longer until a proper repair may be executed. Not only are the normal aluminous or siliceous grades included in this category, but also those of chromic character. Such cements offer a very ready means of effecting repairs, but may prove to be somewhat costly, and where a "compo" of stabilised dolomite clinker (rubble and cement) will not suffice; a very excellent job may then be effected by the use of fireclay mixed with sodium silicate of heavy grade, such as P.84, which, on setting, will bond almost as hard as concrete and will hold almost as well as a brick.

Heat-Treatment Furnaces

Heat-treatment furnaces, whether heated by gas or electricity, do not normally call for temperatures as high as obtain in forging furnaces, and, accordingly, refractories of more normal character might be employed.

For the most part, therefore, a good-shaped No. 1 quality containing 30-35% alumina would be mostly satisfactory, and is generally employed, but if great strength is required, such as for the semi-hollow bottom to receive the arms of a charging machine, such extra strength could be obtained from a brick of siliceous character rather lower than as given in Table I. Such analysis is shown in Table VI.

TABLE VI.

Silica	SiO ₂	82%
Alumina	Al ₂ O ₃	12%
Titanic oxide	TiO ₂	1.41%
Ferric oxide	Fe ₂ O ₃	0.66%
Lime	CaO	0.54%
Magnesia	MgO	0.48%
Alkalies	Na ₂ O and K ₂ O	1.25%
Loss on ignition		0.25%
Refractoriness		1,690° C.

Where the hearth, however, is made suitable for conveyer-type operation, it is sometimes advisable to use sillimanite blocks fastened to the conveying mechanism. On a solid-hearth bottom which suffers abrasion silicon-carbide may usefully be employed, as this resists abrasion better than most other types.

Insulating Materials

In these days of fuel economy some reference to the question of insulation is necessary. In the main, there are two types of brick available, one being that of lightweight character produced from the natural diatomite deposits, and which are capable of temperatures up to approximately 900° C. The second type is really better described as an insulating refractory, as it is capable of temperatures up to approximately 1,350° C. on the hot-face.

Returning to the standard, or natural grade as it is usually described, these must be protected owing to their fragile nature, and can therefore be employed only where a 14-in. wall is possible, and even then this is not too satisfactory, as such would imply three separate courses without bonding, so that the ideal would be a 9-in. inner face of bonded firebrick, followed behind by 4½-in. single-course wall of insulating brick, with a further 4½-in. thick protection of firebrick behind.

One might well suppose that the obvious place for insulation would be on the walls or arch of the combustion chamber, but this is not the case, as it invariably leads to the very early failure of the structure, as apparently it is essential for a certain amount of radiation to take place to prevent the inner surfaces from dripping, if not melting completely. The correct place for insulation application, therefore, is on the heating chamber in which the actual work is placed, and the material should be built around walls, as well as arches, with at least one course in addition beneath the hearth, although this latter must needs be well away from any risk of slagging action.

With the insulating refractory, however, whilst their insulation value is naturally rather lower by reason of the addition of refractory material, their greater strength makes them eminently suitable for direct use in both gas- and electrically-fired equipment, and walls, arches and doors should be constructed of this material for the greatest economy in heat losses.

The mistake should not be made, however, of endeavouring to build too great a thickness of insulation, as this will result in defeating the object. Inasmuch that the amount of radiation is normally proportionate to the

surface area exposed, whilst heat losses may be reduced by including insulation, such saving becomes reduced in extent if the area is correspondingly increased by the larger structure necessary to accommodate the insulation, and losses will take place despite the additional expenditure having been made.

Salvage

In conclusion, no user of refractories should discard as rubbish his worn-out firebricks removed from a

furnace structure. These should be cleaned and sold for the manufacture of grog and other purposes, and if it is felt that the labour cost is too great to warrant such attention, there are usually, particularly in the Midlands area, contractors who will gladly visit your works and pay for the privilege of acquiring unwanted material, and carry out all the necessary dressing and haulage in order to acquire the uncontaminated portions.

Metallurgical Study of Some Control Units from Enemy Aircraft

This report, submitted to the Committee on Non-Ferrous Parts of Enemy Aircraft and published here by permission of the Ministry of Aircraft Production, reveals the fact that a wide range of materials has been employed for both bellows and capsule types of units. With some exceptions materials correspond closely with those used in British instruments, although K Monel, sometimes used for capsules in Britain, was not found.

A TOTAL of 11 diaphragm capsules and bellows fittings of control units, together with one sample of tubing from a Bourdon gauge, have been examined with principal reference to materials and manufacturing methods. The essential information about these units is summarised in Table I, and a fuller description of their function is as follows:—

Items 1a and 1b.—By-pass controls on coolers. These are temperature-sensitive capsules, controlling valves to by-pass oil from the cooler when the oil is cold.

Items 1c, 2a, 3b and 3c.—These are pressure-responsive

capsules, controlling throttle positions through oil-servo mechanisms.

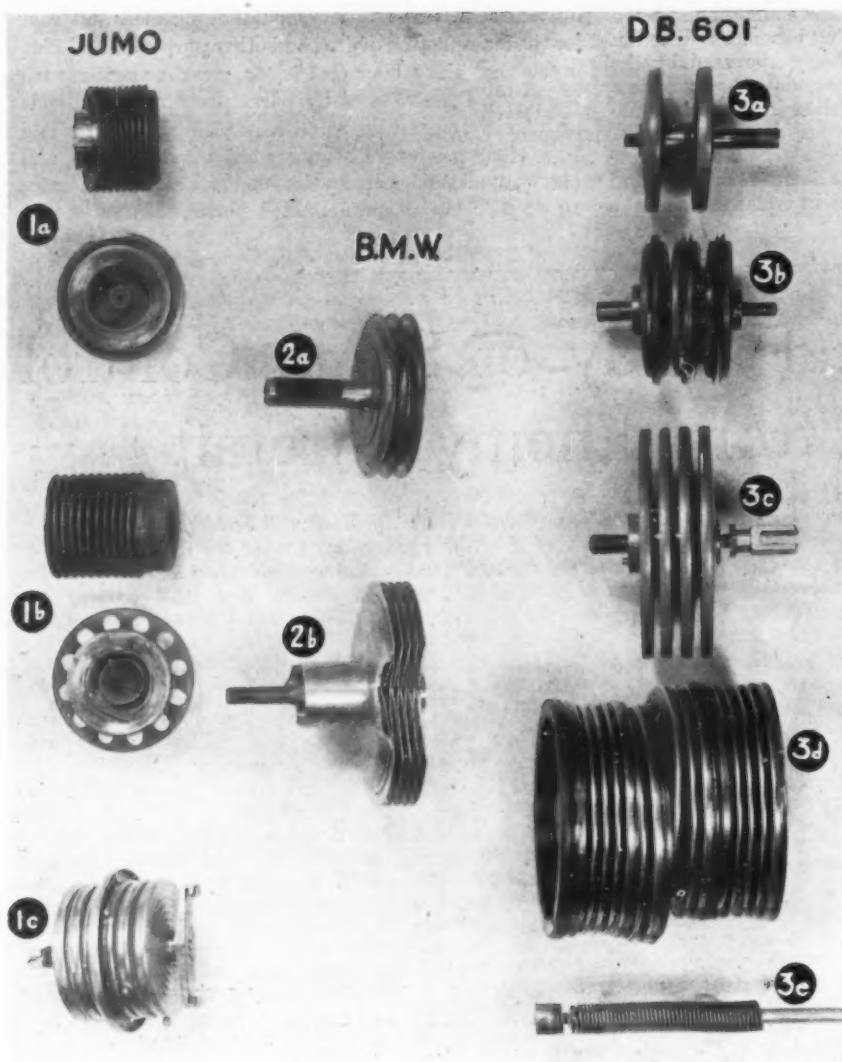
Items 2b and 4.—These are pressure- and temperature-sensitive capsules, controlling fuel-metering pump plungers through oil-servo mechanisms.

Item 3a.—This is a barometric pressure-sensitive capsule which controls the hydraulic fluid circulation through the hydraulic coupling on the blower driving shaft, through a valve to vary the blower speed.

Item 3d.—This is a barometric pressure-sensitive capsule, which controls a fuel-metering pump through linkage.

TABLE I.—SUMMARY OF ESSENTIAL DATA.

Description.	Nominal Composition.	Analytical Results.							Form and Dimensions.	D.T. Hardness.
		Cu.	N.	Zn.	Sn.	Mn.	Fe.	Other Elements.		
<i>Group 1</i> —from Jumo 211 Engine.										
1a Viscosity control unit, oil system	80/20 brass	—	—	—	—	—	—	—	Bellows type, 0.007 in. thick	70
1b ditto	80/20 brass	79.7	Nil	20.0	—	—	—	—	ditto	74
1c Throttle-control unit	Nickel-silver	80.7	18.2	21.3	—	0.29	0.10	—	Capsule, soft soldered, 0.007 in. thick	195
<i>Group 2</i> —from B.M.W. 132 Engine.										
2a Throttle-control unit	Phosphor-bronze	92.1	—	—	7.63	—	—	0.05 P	Capsule formed by stitch welding from strip 0.007 in. thick	182
2b Fuel-injection control unit	Nickel-silver	66.1	12.75	20.3	—	Trace	0.25	—	ditto	182
<i>Group 3</i> —from D.B. 601 Engine.										
3a Supercharger hydraulic coupling	Cupro-nickel	—	—	—	—	—	—	—	Capsule, soft soldered, 0.008 in. thick	96
3b speed control unit	Cupro-nickel	97.4	—	—	—	Trace	0.45	180 Be	ditto	318
3c Throttle-control unit	Beryllium-copper	79.9	19.75	Trace	—	0.12	Trace	Tr. Pb	Capsule soft soldered, 0.010 in. thick	130
3d ditto	Nickel-silver	61.3	12.15	26.1	—	0.10	0.10	—	Bellows type, 0.008 in. thick	120
3d Barometric pressure control unit, fuel-injection system	—	—	—	—	—	—	—	—	Bellows type	—
3e Temperature sensitive element, fuel-injection system	—	—	—	—	—	—	—	—	—	—
<i>Group 4</i> —from Bramo-Fafnir Engine—										
4 Fuel-injection control unit	Phosphor-bronze	91.0	0.06	Nil	7.72	—	Nil	0.11 P	Capsule formed by stitch welding from strip 0.012 in. thick	102
<i>Group 5</i>										
5 Bourdon tube from oxygen pressure gauge, range 0-250 kgs./cm. ²	Beryllium-copper	96.9	Nil	—	—	Trace	0.56	2-30 Be 0-07 Al 0-07 Si	Coiled to dimensions of 1.7 in. external by 1.4 in. internal diameter from oval-section tube measuring 0.3 in. x 0.16 in. x 0.028 in. thickness approximate	233



Item 3e.—This is a temperature-sensitive capsule controlling the fuel-metering pump plungers through linkage.

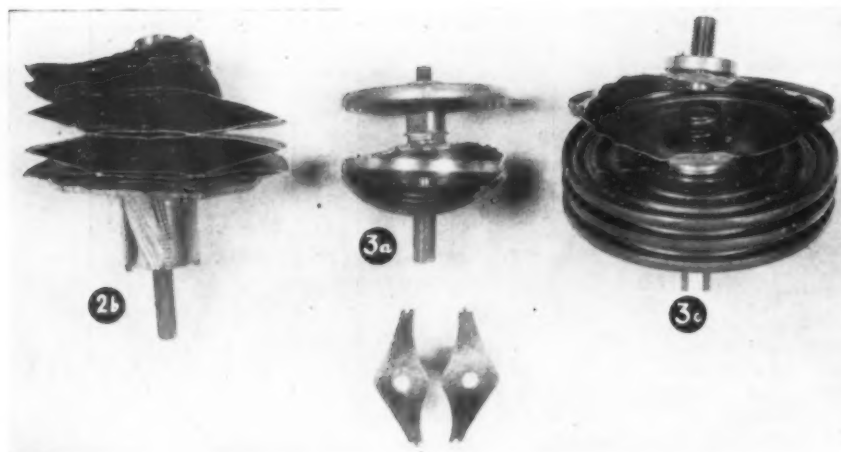
Item 5.—Bourdon tube from oxygen-pressure gauge showing range of 0–250 kgs./cm.²

The materials employed were obviously not standardised in accordance with the application and with one type of unit, diaphragms were found to be of nickel silver, phosphor-bronze, cupro-nickel and beryllium-copper. In another type of unit both nickel-silver and phosphor-bronze were employed.

It was observed that the general method for joining diaphragms to form capsules was by soft soldering round the periphery, but in three instances (2a, 2b, 4a), employing both phosphor-bronze and nickel-silver, the seams were made by electrical resistance stitch welding, probably with an automatic feeding device on the welding machine. Spot welding served to locate different components, and in some instances to fix discs of small diameter to those of larger diameter.

A number of the capsules and bellows are illustrated

Fig. 1.—Capsules and bellows from Jumo 211, B.M.W. 132 and D.B. 601 engines. $\times \frac{1}{2}$



in Fig. 1, while in Fig. 2, at slightly larger magnification, are shown three of the units, 2b stitch-welded and 3a and 3c soft-soldered, partially dissected to illustrate the internal arrangement. This reveals two types of internal springs, viz., leaf type in 3a and helical type in 3c. In Fig. 3 there is shown a close-up of part of capsule 2a having two welded seams and a central disc which is fixed by spot-welding; this shows the neat appearance of the stitch

Fig. 2.—Internal details of three control units.

welding. In Fig. 4 there is shown a section through a stitch-welded seam from Item 4 made of phosphor-bronze.

The Bourdon tube was found to be of regular shape and section, which may partly be attributed to the use of annealed beryllium-copper tubing, afterwards heat-treated to develop its mechanical properties. This component was found to compare favourably with its British equivalent, which is usually of phosphor-bronze, although examination revealed the presence of minute fissures on the inner surface. The D.P. hardness of 333 compares with about 145-180, normally found along the sides and ends of British Bourdon tubing.

The hardness results incorporated in Table I do not call for comment, as they are normal for the types of products and materials in question, i.e., spring temper for capsules and medium temper for bellows. The hardness figures of about 320-330 for beryllium-

copper are of a similar order to those obtainable with K Monel metal, which latter shows somewhat comparable tensile strength and proof-stress values with higher limit of proportionality and modulus of elasticity.



Fig. 3.—Stitch and spot welding on capsule 2a. $\times 2$.

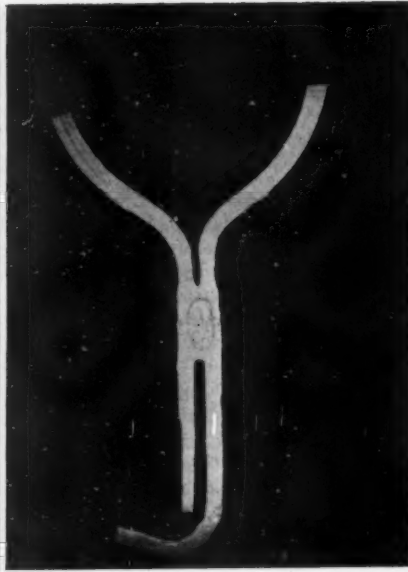


Fig. 4.—Section through stitch-welded seam, capsule No. 4. $\times 10$.

The Spectrographic Analysis of Copper and Copper-Rich Alloys by the Arc Method

IN the spectrographic estimation of impurities in copper and copper-rich alloys, it is necessary to use an arc in preference to a spark, in order that the sensitivity required for the detection of traces may be obtained. The functioning of the copper arc, however, is not properly understood, and no investigation into its fundamental aspects from the analytical point of view has hitherto been carried out. One object of the work recorded in this paper* was therefore to present a qualitative picture of the behaviour of a copper arc, and of impurities present in the electrodes. A second object arose from the nature of the routine samples which are analysed spectrographically. They include a variety of alloys and test-pieces, the size of which may range from large pieces cut from ingots or billets to strips and tubes a few thousandths of an inch thick. It was necessary, therefore, to devise a technique which would be satisfactory for the majority of such samples.

The scope of the investigation was limited to the detection and estimation of numerous impurities, present in quantities generally less than 0.2% in commercial coppers and alloys. For the sake of speed and simplicity, the metals themselves were used as electrodes.

Observations have shown that volatilisation of copper caused by the action of oxygen takes place mainly from the cathode, and that a cathode layer, as normally understood, is not necessary for the maintenance of the

arc. Selective distillation of impurities does not take place when the sample is made the negative electrode, but it does occur otherwise, or when free oxidation of the cathode is prevented. The excitation of arc radiations, whether of base metal or impurities, depends mainly on the density of the cloud of neutral copper vapour diffusing from cathode to anode along with the electron stream.

From the point of view of the theory of the arc discharge, it is considered that the necessary electron density arises more from the action of oxygen on the cathode, which releases electrons concurrently with copper, than from thermionic or auto-electronic emission.

Control of the arc by means of the electrical conditions is not satisfactory, but by bringing the total amount of visible light emitted by the arc to a pre-determined value, as measured with a photo-electric cell and microammeter, more consistent results are obtained. This control allows similar spectra to be obtained from samples of different size and shape, its success arising from the dependence of the excitation of arc radiations on the density of copper vapour, which is brought to a constant value by means of the photo-electric cell. By using this technique it is also possible to apply the same line comparisons to a wide range of copper-rich alloys, with certain limitations which have been noted.

Tables for the estimation of numerous impurities are given, as well as additions and modifications to published lists of arc lines occurring in the copper spectrum.

* By Maurice Milbourne. *Jour. Inst. Metals*, 1943 (October), 60, 141.

Shipbuilding and Light Alloys

By Capt. E. C. Goldsworthy

Some of the considerations arising in the use of aluminium alloys in merchant ships are briefly discussed by the author in a paper recently read before the Institution of Engineers and Shipbuilders in Scotland, the main purpose of which being to indicate some useful lines of investigation and to present a case for the immediate inauguration of a programme of research, so that factual results may be ready when the materials are freely available and the shipbuilding industry reverts to its normal activities. Some interesting aspects of the subject are given in this abridgement.

DURING the war aluminium alloys have been reserved almost exclusively for the construction of aircraft and aero engines and little or none has been used for the merchant ship. In this period, however, the interest in light alloys shown by the shipbuilding industry has increased, and is perhaps attributable to:—

- (a) The force with which aircraft have intruded into our thoughts and conversation;
- (b) The number of shipbuilding firms interested in aircraft construction;
- (c) The effect which post-war transport will have on them;
- (d) The new materials which the shipbuilding industry has been compelled to use, thus making it receptive to new or relatively new materials;
- (e) The surge of the corporate spirit manifest in the shipbuilding industry and the realisation that a strong research organisation is essential if the industry is to survive and make headway.

Manufacturers of aluminium have been preoccupied with the problems of aircraft and aero engines and have given relatively little thought to the shipbuilding industry, which calls for a different approach, technique and staff. Thus, the practical applications of aluminium in this industry have been on a correspondingly small scale and progress has been retarded by the lack of technical liaison. Although both shipbuilder and shipowner appreciated in theory the value of weight reduction, any potential advantages from the use of aluminium alloys were clouded by the high first cost and, further, faith in the material was not sufficient to advance designs incorporating these alloys. But the shipbuilding and aluminium industries will be faced with a common problem at the end of the war—to keep their workmen and plant employed and to extend their markets. Shipbuilders know that this can only be achieved by building the finest ships at the most economical price and that to do this extensive research must be done. The aluminium industry is ready to co-operate unreservedly in any investigation towards that end.

Materials and Structures

The shipbuilder demands a material which is strong, easy to work, form and assemble, yet which will give a rigid structure and stand up to marine conditions. Aluminium alloys satisfy these conditions provided that the correct alloys are used, and used only when they can be justified; that the structure is designed for them or that maximum advantage is taken of their

characteristics; and also that the correct technique of employing them is understood by shipyard and user.

The alloys most suitable for the construction of ships have been detailed by Devereux and Telfer,* when they were given the generic term "Navalium." These alloys are available as forgings, castings, plate and sections suitable for the most exposed positions. The non-heat-treated alloys are more likely to be used for plates and sections, to avoid the additional cost involved in using heat-treated alloy, but for forgings and some castings heat-treated alloys would be preferred. The term "Navalium" is used to cover a range of alloys, but it is possible that this could be reduced to two or three, the specifications for which would be approved by the recognised authorities and on which shipbuilders would order their materials.

Special Characteristics of Aluminium Alloys.—The major differences from steel to be considered when designing in light alloys are, firstly, the specific gravity, which can be taken as 2.68 or 170 lb. per cub. ft. Secondly, there is no sharply defined yield-point so that the proof stress is that which is just sufficient to produce a permanent elongation equal to a specified percentage of the original gauge length. In this country, the arbitrary standard adopted for light alloys is the 0.1% proof stress, which is defined as "the maximum load per sq. in. which, when applied to a tensile test-piece for 15 secs. and removed produces a permanent extension of not more than 0.1% of the gauge length" (i.e., 0.001 in. per in. of gauge length). Thirdly, the lower modulus of elasticity E , of approximately 10×10^6 lb., or 4,500 tons per sq. in., about one-third that of steel, results in about three times the deflection of identical steel beams similarly stressed. The resilience, however, increases with deflection, and the stresses from impact are therefore appreciably reduced. Too much deflection is undesirable, but what constitutes too much depends on all the circumstances, and in the majority of shipbuilding applications the extra deflection may not be undesirable, whilst in some cases it may be beneficial.

For similar deflections, the moments of inertia of the aluminium alloy beams must be increased to three times those of the steel beams—i.e., in inverse proportion to the values of E for the two materials—but, even in special instances, it has been shown that the increase of inertias brings the weight of aluminium alloy beams to only about 50% of that of the steel beams. Thus, where a reduction in structural weight would clearly give an

* "Light Alloy Ship Construction." W. C. Devereux and Dr. E. V. Telfer. *Trans. Inst. Naval Arch.*, 1939, **81**, 280.

increased earning capacity, a thorough investigation in light alloys is justified.

Hulls.—There is at present no satisfactory anti-fouling paint commercially available for aluminium, inasmuch as the most effective anti-fouling paints rely on the presence of copper or mercury compounds for the necessary toxicity, and both of these actively stimulate the corrosion of all aluminium alloys by galvanic action. Hulls in light alloys, therefore, can only be recommended for services where the ships are little affected by fouling or where they have a regular period of cleaning. Nevertheless, hulls of some 200 small vessels, up to a length of 103 ft., have already been built and been proved satisfactory in service.

Superstructure.—Above the waterline no technical difficulties oppose their structural use, and amongst the latest examples is the *Fernplant* (1939), in which 14 tons of light alloys are stated to replace 40 tons of steel on the bridge deck. This is the first sea-going ship to use them in the superstructure, and although the small tonnage used may be of little value from a profit-earning consideration, it should provide practical evidence of the suitability of the material and method of construction under deep-sea conditions. Three New York ferries are reported to have 30 tons of aluminium alloys in the construction of their shade decks, giving a saving of 39 tons, or 2% of the displacement, which, among other advantages, is a valuable contribution to their stability.

Value of Weight Saving

As a result of investigations, it has been stated that each ton saved leads to a reduction of 3 tons in low-speed vessels and up to 6 tons in destroyers. One investigator considered it possible to reduce the weight of a destroyer by some 50 tons, using aluminium alloys for the construction of erections and such parts as do not contribute to the main longitudinal strength, together with numerous internal fittings, giving thereby an increased metacentric height of about 9 in. in the loaded condition and increasing the speed at full power by over half a knot. It is also reported that the U.S. Navy, in conjunction with the Bath Iron Works, Maine, has designed a destroyer in which light alloys are used extensively, where the displacement of a 275-ft. vessel is reduced to under 1,000 tons with the same fighting power of current designs, yet with a speed of 52 knots.

Vessels which appear to gain considerable benefit from a reduction in light ship weight are those operating in shallow waters, particularly if service conditions limit other dimensions. They are often restricted in operation owing to shallow water, are limited to the passengers and/or freight they can carry, and, since the majority are engaged on ferry services or pleasure traffic subject to wide seasonal fluctuations, they have either to be assisted with additional craft, refuse potential business, or run many additional trips during the peak load periods to clear the traffic. Any improvement in carrying capacity in the peak seasons, particularly if accompanied by a reduction in displacement in off seasons, must result in greater profit to the owner, provided the additional returns outweighs any higher first cost, capital charges and maintenance costs.

For these reasons, and because of the anticipated world-wide demand for vessels of this class, the author considers, in some detail, three different types, the investigations being confined to erections and fittings above the upper deck. The first was a proposed passenger

vessel, 180 ft. in length, whose construction in steel was difficult on the draught specified. It was found that by converting the steel superstructure to aluminium alloys there was a saving in weight of 21 tons, approximately 10% of the light displacement, which was in itself a sufficient reduction to enable the vessel to be built on the draught required and with the same steel hull. The ability to build the vessel and the additional advantages in stability, speed or power consumed were given with an estimated increased first cost of the whole ship of about 6%, even at to-day's prices of light alloys and steel.

Another example was a passenger and car ferry, 148 ft. in length. This investigation was divided into two parts, the first being a pure conversion of the superstructure, which gave a saving in weight of 15 tons when using light alloys, or 6% of the light displacement. The second part was to determine whether this reduction in the light ship weight could be used to increase the earning capacity of the ship without altering her dimensions. The light alloy superstructure was accordingly raised 8 ft. to free the decks for extra vehicles and packages, and, when due allowances had been made for the additional structure required to support the raised housings, bridge, etc., and for additional bulwarks on the main deck, there was a saving of 12 tons, or 5% of the light ship weight. An examination of the economics of the new design, taking into account the present cost of materials, the increased depreciation and interest on higher first cost, indicated that if the enlarged capacity was used for only a relatively short time in the course of a year, there would be a considerable return to the shipowner over the normal life of the vessel.

In the conversion of the superstructure of a 220 ft. passenger vessel, there was a saving of 11 tons, about 2% of the light displacement, which might at first sight appear to be of no practical or economic value. But, the question is asked, is it not possible to use this weight to design a better earning ship? Vessels whose earnings have to be made in a comparatively short period cannot afford to run only partially full. Every effort should be made to allow for varying weather conditions by the provision of good covered-in accommodation. It is suggested that by using light alloys the same standard of comfort can be offered passengers as in shore transport, and additional deck-houses could be erected without adding to the light displacement or affecting the stability in the load condition.

These investigations were not intended to be exhaustive or scientifically determined. In each instance the weight reduction was approximately 50%, but it is believed that designs based on the stresses and using light alloys to their best advantage would reduce this still further. Nevertheless, they indicate how the saving in weight by the use of aluminium alloys in the superstructure alone might assist in building a better ship, the three main avenues being:—

- i. To increase the service availability by a reduction in displacement;
- ii. To increase the earning capacity; and
- iii. To provide improved amenities to attract passengers.

Non-Structural Applications

Apart from the structural use of light alloys, they may be usefully employed in the make-up of accommodation where the demand for additional space and

comfort aggravates the stability problem, whilst the risk of fire limits the choice of materials. Cabin partitions should have the necessary rigidity and freedom from drumming, be light, fireproof, and possess good thermal and sound insulation, and it is believed that a partition consisting of aluminium alloy sheet facings, bonded to a non-odorous fire-resisting filling, will provide the solution. Those familiar with the modern warship and passenger vessel know the extent to which aluminium alloys are used, both in the wrought and cast forms, for fittings and decorative items, and the progress made in colour anodising will, it is anticipated, increase the use of light alloys for such purposes.

Lifeboats in light alloys were rapidly achieving a justifiable popularity up to the outbreak of war. They are fire-resistant—a factor of vital importance now appreciated—resist impact damage due to their low modulus, and, by virtue of their light weight, are easier to handle and contribute to the stability of high-sided vessels. Masts, ventilators and funnels have already been used and stood up to conditions satisfactorily over a period of years. For many deck fittings light alloys are particularly suitable, the material having a consistently good appearance and the required strength with either castings or forgings. The lower modulus gives an increased resistance to shock, which is of value to certain deck fittings.

Machining—Main and Auxiliary

For machinery in exposed positions, the alloys of maximum corrosion-resistance should be used, but for parts to be permanently installed in the engine-room the choice of alloys is considerably widened. Light alloys perform a threefold purpose when applied to internal combustion engines; they increase efficiency due to reduction of momentum; they are of value in inducing thermal uniformity, and when used extensively a considerable reduction in weight can be obtained. The part which light alloys play in the construction of the high-powered petrol engine is well known, while their use in Diesels is rapidly growing. A consideration of the total amount of main and auxiliary machinery in the modern vessel suggests that an extensive use of light alloys would provide considerable reduction in weight with a substantial effect on the operating costs and pay load, particularly in shallow-draught vessels.

Reference is made to a number of properties and technical characteristics, in addition to mechanical properties, of typical aluminium alloys suitable for marine purposes which will require investigation, and some of the most important include jointing, corrosion, and economic questions, and the latter question is not the least important. On this subject the author states that, if aluminium alloys are to be considered, an indication of their future price will be of value, and this is determined by the cost of the metal and the cost of rolling the sheet or extruding the sections.

With regard to the first item, the 1939 international selling price of virgin aluminium ingot was £92 per ton. This has since been reduced by 25% in the U.S.A. and Canada, and it is anticipated that this decreasing trend will continue. In fact, recent statements in the Canadian Parliament gave 6 cents per lb., say, £30 per ton, as being the present production cost of ingot, made possible by the cheap power available from the new hydro-electric power stations and the vast reduction plant

facilities. Canada's annual production capacity alone is 500,000 tons, equal to the whole world production in 1939, whilst that of the U.S.A. has gone up sixfold and is approximately 1 million tons. The estimated world consumption is 3 million tons, which, on a pre-war steel capacity of 150 million tons, gives a ratio of 1 : 18 on a volumetric basis. Aluminium thus ranks second to steel, and its production is a contributory factor in the economic stability of Canada and the U.S.A., and if markets are to be found the price must be competitive with other materials.

With regard to the second item, it is anticipated that when conditions return to normal there will be a substantial reduction in the cost of rolling sheet and extruding sections due to the writing down of the high development and capital charges, the enlarged production facilities and the improved technique. Furthermore, other factors which have to be considered in assessing the cost of light alloys compared with steel are ease of machining, forming and handling. These should all be favourable to light alloys, as also will be upkeep costs due to the better corrosion-resistance of the material with, consequently, less painting. The break-up value of light alloys, particularly for the "Navalium" types, is relatively high and must be offset against the initial price differential with steel. But it is the ingot price which is the main determining factor, and at present, as with all other materials, aluminium is controlled. The Government has stated that the first consideration in post-war reconstruction must be the full employment of capital, plant and labour, and, as a necessary measure to that end, will continue to control materials. The Government, therefore, is anxious that these comparatively new materials be used to their fullest extent for the benefit of the country as a whole and is equally interested with the aluminium producers and aluminium alloy manufacturers to bring the price down to the lowest level possible. We can be confident, therefore, that alloy sheet and sections will be available at a price much below the 1939 level, but no matter what the eventual price level may be, this consideration should not be allowed to stand in the way of research and development investigation.

Zinc Pigment Development Association

AN association, to be known as the Zinc Pigment Development Association, has been formed, comprising the leading British producers of zinc pigments. The principal object of this Association is to encourage and develop the uses, actual and potential, of zinc pigments by all appropriate means, particularly by making their properties and applications more widely known.

The following is a list of the founder-members:—Amalgamated Oxides (1939), Ltd., Barking Zinc Oxide, Ltd., James M. Brown, Felling Zinc Oxide Co., Fricker's Metal and Chemical Co., Ltd., McKechnie Bros., Ltd., The Newcastle-upon-Tyne Zinc Oxide Co., Ltd., Orr's Zinc White, Ltd.

The Association will work in co-operation with the Zinc Development Association of Lincoln House, 15, Turl Street, Oxford (Tel.: 48088), and its offices are at the same address.

Anodic Films on Aluminium Alloy Parts of German Aircraft

A summary of investigations conducted by the Staff of the Metallurgy Division of the Royal Aircraft Establishment, submitted to the Committee on Non-Ferrous Parts of Enemy Aircraft, and presented to readers on behalf of the Ministry of Aircraft Production.

SAMPLES of anodically treated aluminium alloy parts have been taken from several German aircraft, chiefly from the airframes. These have been examined for type and nature of the anodic films. In all 19 parts have been examined. The names of the parts, the aircraft from which they were taken, the appearance of the anodic films, and the corresponding type of British material are indicated in the accompanying table.

Scratch tests and bend tests showed that the films were adherent, hard and brittle. The film on the cock body (Item 19) was very hard.

Chemical Tests

Chemical tests were made on samples of the films after removal of the films by scraping. Sulphate was detected in all the films except that on the cock body. Chromium was detected in all the yellow films, but not in the buff-coloured film on the cock body. It is evident that all the films except that on the cock body had been produced in sulphuric-acid baths, and that the yellow films had been sealed in dichromate solutions.

Observations on Film Thickness

Observations on film thickness were made by removal of the films by chemical means, and by microscopic examination of transverse sections.

A boiling solution of phosphoric and chromic acids was used as recommended by J. D. Edwards,* since

sealed films are not readily removed by cathodic treatment in hot chromic-acid solution. The thickness of the films was calculated from the loss in weight on stripping. In the calculation of film thickness the density of the film was assumed to be 2.8. It is known, however, that the density of anodic films on aluminium alloys varies with the conditions during formation of the film, etc., and that the values obtained in this way vary by $\pm 25\%$ from the actual values of film thickness. The results are given in the accompanying table.

Transverse sections of the samples were prepared and the anodic films were examined microscopically. The examination revealed no unusual feature. The microscopical method of observing the thickness of anodic films on aluminium is generally considered to be the best. The results obtained on the present samples are given in the accompanying table.

Comments and Conclusions

The anodic film on the cock body appeared not to have been sealed. The film was very hard, was 15 microns thick, and appeared to have been produced by the "Eloxal GX" process—i.e., by D.C. treatment in an oxalic-acid bath. As the plug (steel) of the cock seats directly upon the light alloy body, a hard anodic film on the latter should be of advantage in this application. Part of the cock body was cleaned and re-treated in an 8% oxalic-acid bath at 60 volts, 18°–20° C., 60 mins. The new film resembled the original one, but was 22 microns thick. The anodic films on the other items examined had all been produced in sulphuric-acid

* A.S.T.M. Preprint No. 19, 1940.

ANODIC FILMS ON SAMPLES TAKEN FROM GERMAN AIRCRAFT.

Sample.	Aircraft.	Date of Capture.	Component.	Material and Relevant British Specification.	Appearance of Film.	Thickness in Microns.	
						By Chemical Method.	By Microscopical Method.
1	Ju 88 A4	23/3/42	Strip stringer from wing	Wrought Dural (5 L3)	Smooth, yellow, bright	13	10
2	"	"	Hat section stringer, fuselage	" (5 L3)	"	9	7
3	"	"	Tapered root, wing spar	Extruded " (6 L1)	Dull deep yellow	13	13
4	"	"	Tapered T longeron, fuselage	" (6 L1)	"	8	5
5	"	"	T-section, main wing spar	" Al. Alloy (DTD 364 A)	Dull pale greenish yellow	6	9
6	"	"	Oil pipe from fuselage	Wrought Anticorodal	Smooth, yellow, bright	16	15
7	"	"	Mounting ring, nose gun	Cast Al. Alloy (9% Si, 0.5% Co)	Rough, dark grey	10	15
8	Do 217 E2	12/2/42	Oxygen bottle	Wrought Dural (5 L3)	Inner—pale yellow Outer—blue	5 6	7 7
9	"	7/2/42	Lower flange, rear wing spar	Extruded Al. Alloy (DTD 364 A)	Pale yellow	6.4	9
10	"	"	Fuselage skin	Alclad Sheet (1.38)	"	6.3	7
11	"	"	Control tube	Wrought Dural (5 T4)	Yellow	4.6	5.0
12	"	"	Oxygen bottle	" (6 L1)	Inner—pale yellow Outer—blue	— —	7.5 8.0
13	Ju 88 A4	18/1/43	Tapered compensating piece lower wing spar	Extruded Dural (6 L1)	Yellow	—	7.5
14	"	"	Control tube	Wrought Dural (5 T4)	Bright yellow	—	13.0
15	"	"	Pipe coupling	Cast Al. Alloy (2% Mg)	Pale yellow	—	6.0
16	"	"	Hose-end fitting	Wrought Dural (5 T4)	Very bright yellow	—	11.5
17	Me 210	6/9/42	Circular plate, flexible tank orifice	" (6 L1)	Bright yellow	6.4	9.0
18	"	"	Control tube	" (5 T4)	Pale yellow	—	7.0
19	He 115 BB	"	Cock body	Al. Alloy Casting 4.85% Mg, 1.11% Si	Buff	—	15

electrolytes. It is therefore most probable that the D.C. sulphuric process, known in Germany as the "Eloxal G.S." process, had been used. Most of these films had been sealed by treatment in dichromate solutions to provide increased efficiency of protection. The thicknesses of the films, 5 to 15 microns, are not unusual for films produced by this method. The depth of colour of the yellow films appeared to be roughly proportional to the thickness of the films. The films on the external surfaces of the oxygen bottles had not been sealed by dichromate treatment but had been dyed blue.

The film on the gun-mounting ring casting was of dark-grey colour, due to the aluminium alloy containing a high percentage of silicon.

Anodic treatment of aluminium aircraft parts in Germany has been described in an article in "Dornier Post."† The conditions of operation are 15 to 20 amp. per sq. ft., 11 to 22 volts, 16° to 24° C., and sulphate of aluminium content of bath not greater than 45 grms. per litre. Hot potassium-dichromate solution (90°-95° C.) is used to seal the films.

† "Aircraft Production," October, 1942.

Fuel Economy in the Foundry

MANY aspects of the problem of fuel economy were discussed at an all-day conference on industrial fuel efficiency, held recently in Newcastle-on-Tyne, at which it was stressed that the production position was becoming increasingly serious. Mr. Tom Smith reminded the delegates that every time our airmen dropped 4,000 tons of bombs on enemy territory, their manufactures and transport had consumed about 40,000 tons of coal. Increasing demands are not merely for greater quantities of coal but for special qualities. Discussing furnaces and furnace design, Mr. H. C. Armstrong said, in every case the first step is measurement, and if people can be trained to measure the fuel they are using they will become fuel conscious. Once this has been accomplished, saving methods will develop for getting better efficiencies.

An interesting and informative discussion on fuel economy in the iron foundry was given by Mr. Colin Cresty, who pointed out that this subject is rarely a popular one in iron foundries for two reasons. In the first place, foundrymen are very conservative and loath to change well-established practice which may have taken years to build up. In the second place, fuel is not a matter of major importance from the financial point of view, often forming only 5% of the total cost thereof, so that even a material fuel saving only represents a negligible portion of the total cost. There are, however, directions in which, by organising certain work with a fuel economy bias, considerable progress may be made without necessitating any vital change in practice.

So far as cupola practice is concerned, every founder should ask himself the question, "Am I melting more metal than is absolutely necessary to produce my output of castings?" and should not answer it until he has investigated the various factors which bear upon it. The ratio between output of castings and total metal melted can be expressed as "percentage yield." Many founders do not know their yield figure nor appreciate its importance, because all excess metal is returned to stock as scrap, apart from the very small amount actually lost in melting. The fact is often lost sight of that coke has been consumed in melting this excess metal. Yield figures necessarily vary with the class of work and may be from 35% in the case of certain types of light castings to over 80% in foundries doing heavy plain work. Apart from the class of work there are a number of smaller factors common to all foundries, and a good yield figure reflects the care which has been taken in planning many small items. An increase in the

yield figure results in an immediate fuel saving, and in a typical case a rise from 40% to 60% reduced the charge coke per ton of output from 5 cwt. to 3 cwt.

The next item of importance is to reduce the number of melts. A direct saving is achieved by having a small number of long runs instead of a larger number of small runs. Thus, by melting on five days each week instead of six the fuel saving is 5½%. A graph was shown illustrating the increase in yield for one foundry from 54% to 64% since the outbreak of war. If the yield had remained at the lower figure the whole time, the coke consumed would have been 900 tons more than it actually was.

A final section dealt with economy in core and mould drying. For maximum economy, as few stoves as possible should be employed by filling those in use to capacity. This may involve extra lifting of moulds and cores, but it is unquestionably one of the chief factors in fuel saving. Each stove should be fitted with a recording pyrometer so that drying may be done on a definite temperature/time basis. The fuel consumption of each unit should be ascertained and checked periodically. This leads to a greater interest being taken in the matter by all concerned, including the operatives. Also, it will probably show that some stoves are more efficient than others, thus leading to investigations as to the reasons.

By reviewing the records of a number of stoves in two foundries, the fuel consumption per thousand cubic feet of stove space per overnight drying period was obtained. The results were tabulated for four different types of stove and ranged from 1½ cwt. to 3½ cwt. of coke. Another frequent cause of waste is the consignment of partly burned fuel to the rubbish heap. Much of this can be recovered and used in drying stoves. It is also a great advantage to have at least one stove which is capable of using the breeze which inevitably arises from the handling and storage of coke.

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THE directors of Thos. Firth and John Brown, Ltd., have invited applications for the appointment of Principal of the Brown-Firth Research Laboratories. The duties of the Principal include those of technical adviser to John Brown and Co., Ltd., Thos. Firth and John Brown, Ltd., and their associated companies. Applicants, who should be of high academic standing with wide experience in the metallurgy of iron and steel, are asked to write to the Secretary, Thos. Firth and John Brown, Ltd., Sheffield.



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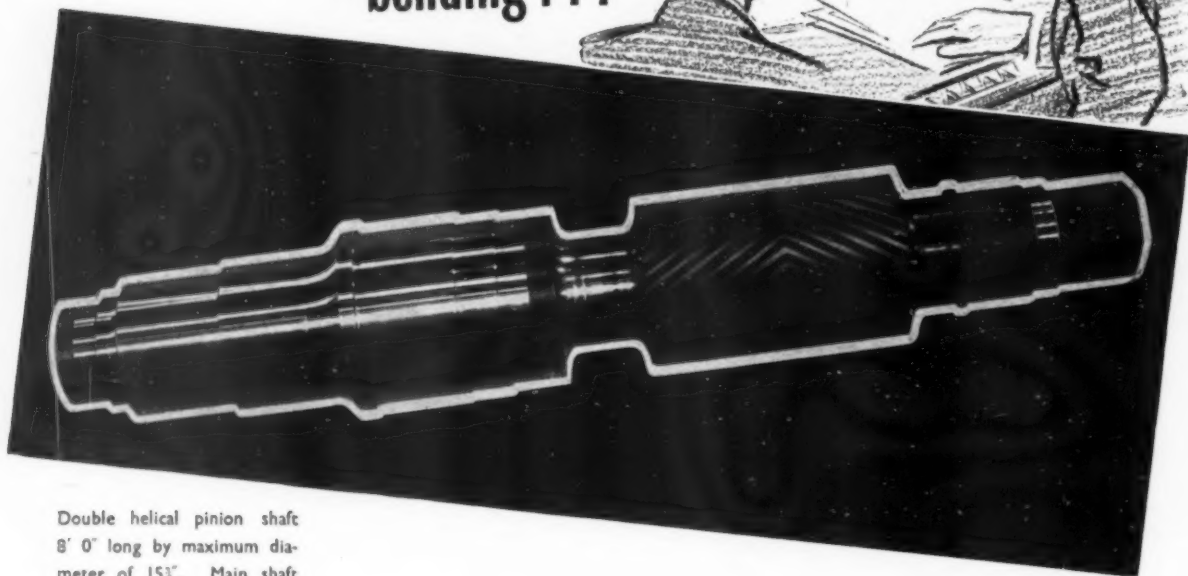
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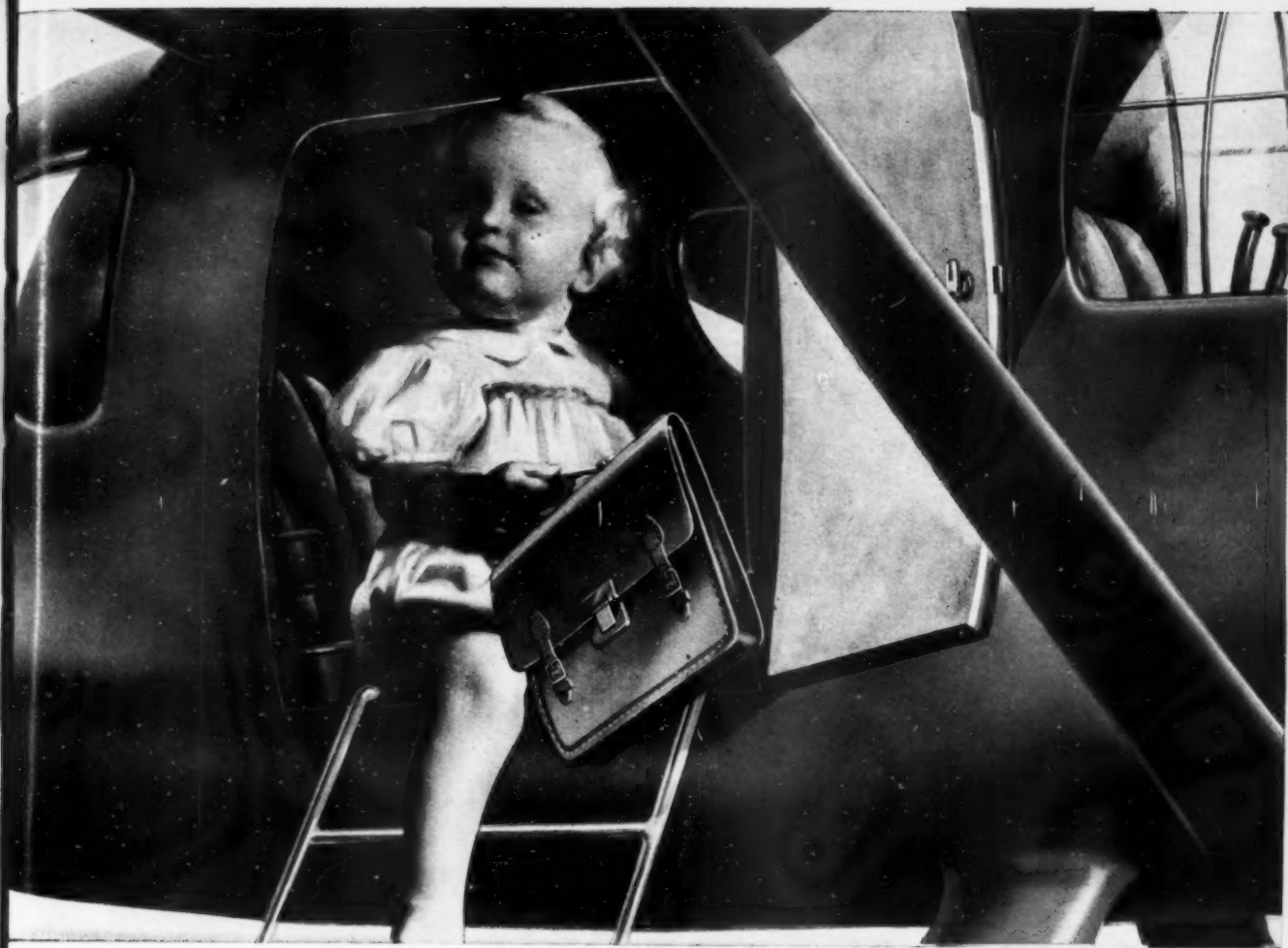
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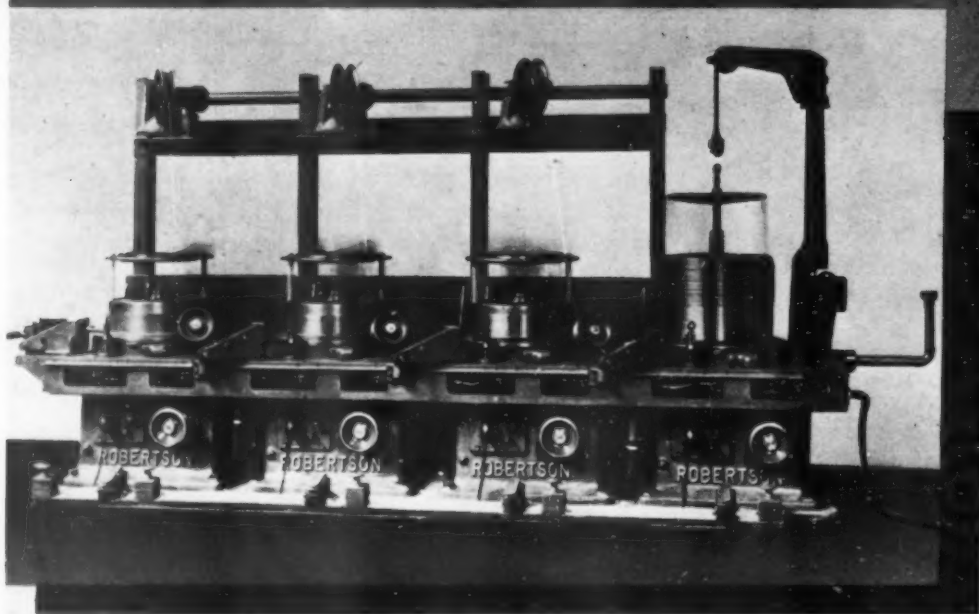
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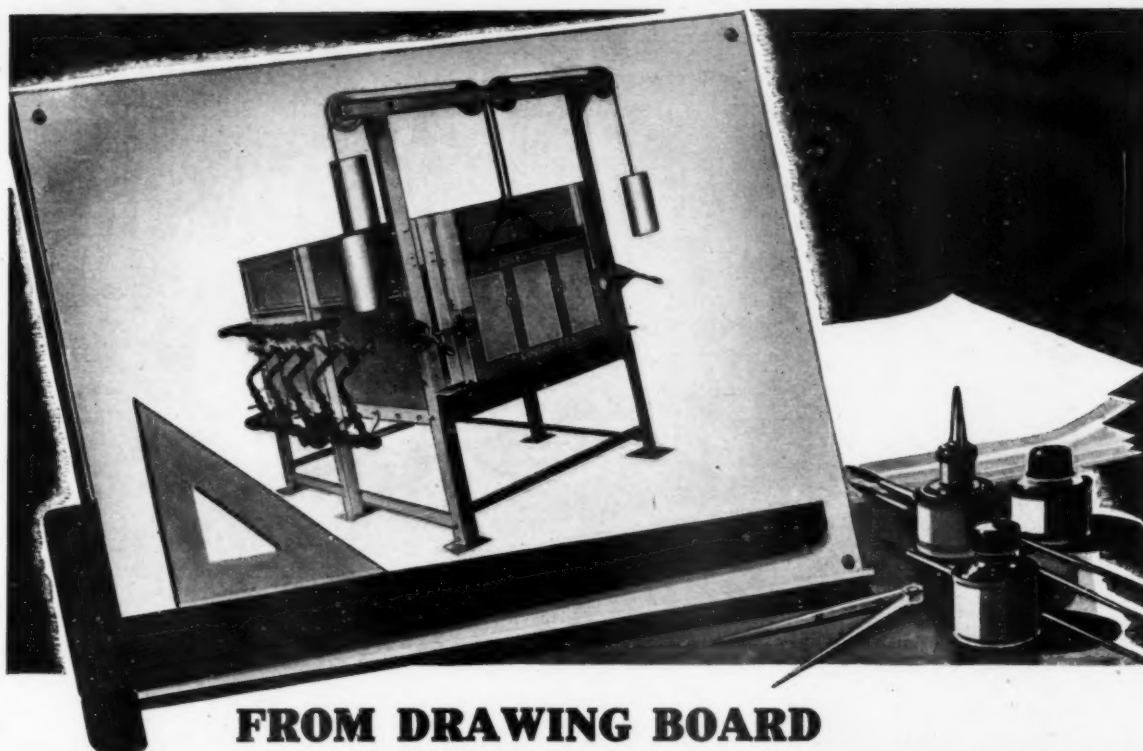


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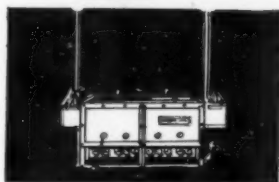
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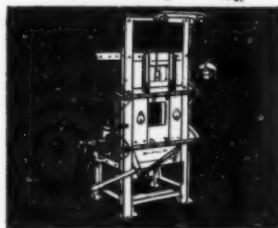
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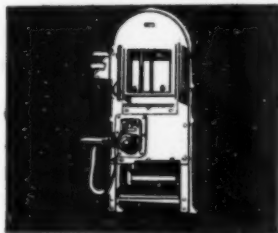
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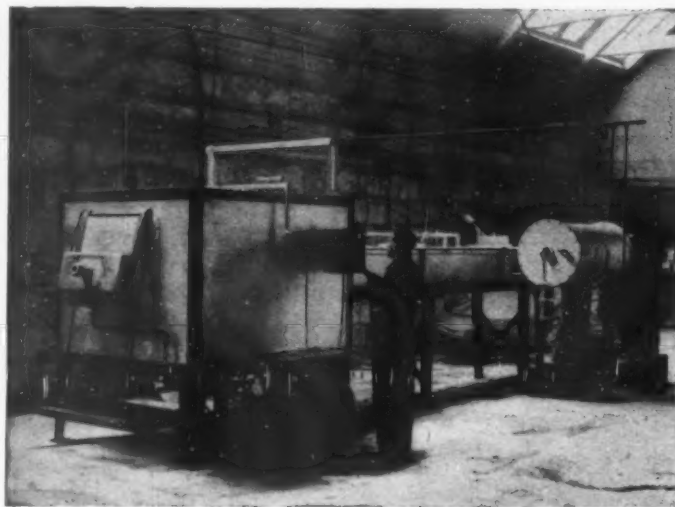
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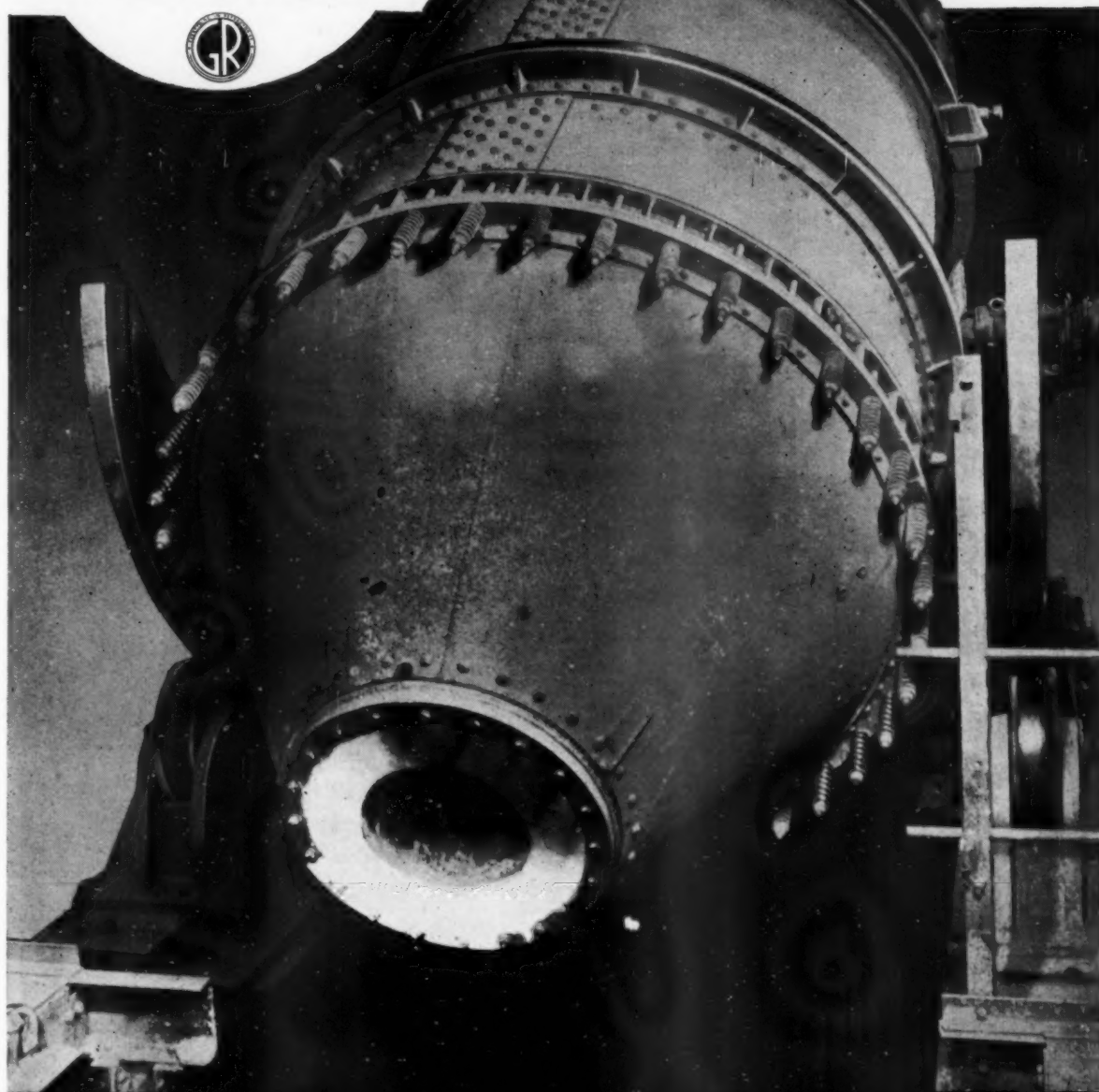
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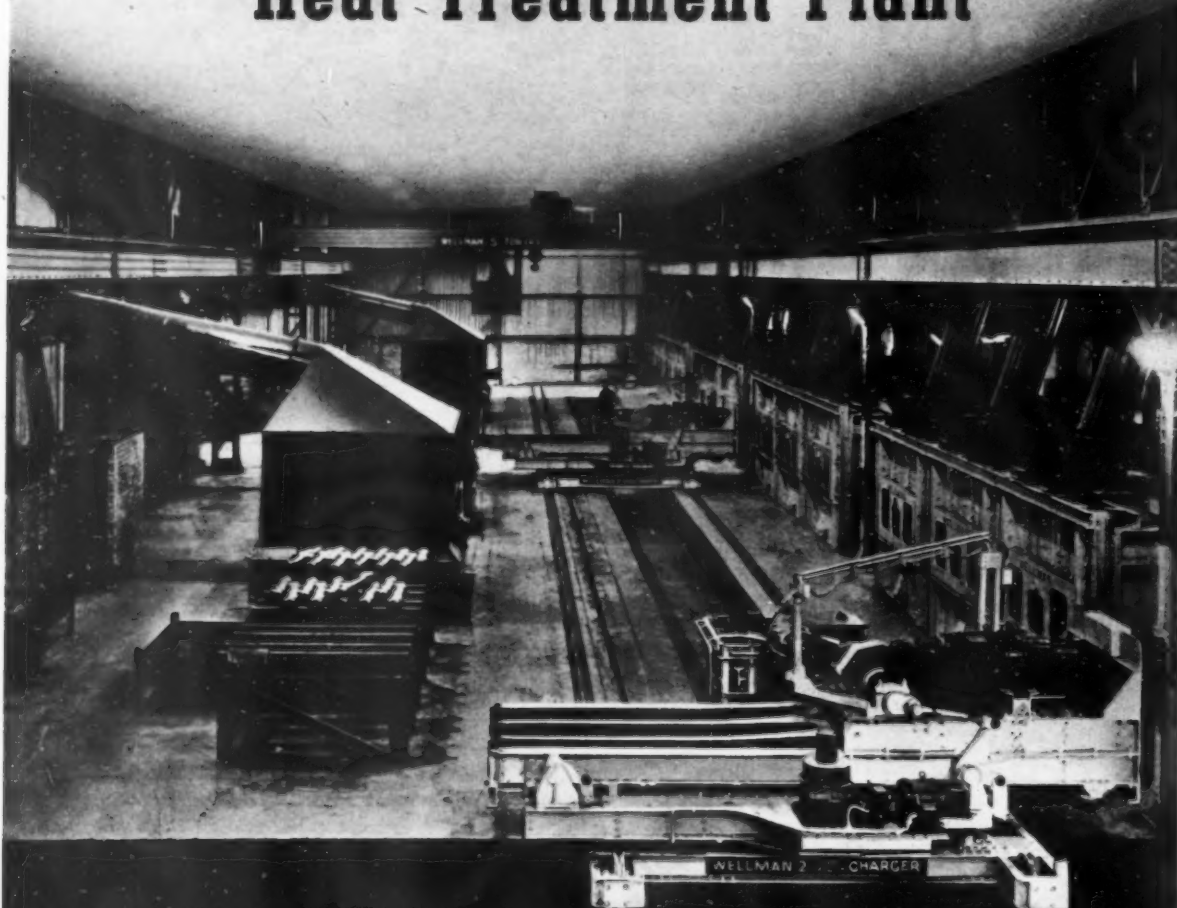
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The British Iron and Steel Industry

A Brief Review of Developments Since the Opening of Hostilities

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In times of peace it is possible to indicate outstanding developments in the course of a year's work which can be regarded as achievements leading to progress; in a world war, however, so many changes become necessary, and problems accumulate so rapidly, that greater speed in reaching satisfactory solutions becomes essential, especially when they are concerned with a key industry, such as the iron and steel industry, and for obvious reasons these solutions cannot be given in detail, nor can those be singled out which can be regarded as responsible for progress during the present year. This outline of developments, therefore, should be regarded not as an indication of progress, but rather as a result of changes war conditions have imposed upon the industry.

WE are so accustomed to a plentiful supply of iron and steel in peace time that we are inclined to overlook the increased importance of these materials in times of war, yet a modern state's ability or otherwise to make war depends primarily upon its steel-producing capacity. For this reason students of war, before 1940, had expressed serious doubts as to whether Italy or even France could really qualify as great powers. At that time the last published figures (1937) gave steel ingot production in Italy as being 2,050,000 tons, in France 7,920,084 tons, Britain 12,984,000 tons, as against Germany's 19,848,824 tons, Russia's estimated 26,000,000 tons, and the United States' 50,586,701 long tons. Japan, the producer of 5,720,000 tons per annum, including Manchukuo's output, was also regarded as a doubtful contestant for inclusion in the ranks of the great military powers. The actual course of the war has not entirely reversed the validity of this argument, as Italy and France have fallen and Japan has not yet been fully tested. It has been estimated in America that 4 tons of steel are required annually per fighting man. Taking this very rough figure as a ready reckoner, on pre-war steel ingot production Japan was reduced to a fully equipped army of a million-and-a-half men, France to two-million men, Britain three-and-a-quarter, Russia six-and-a-half million, Germany five million, and America twelve-and-a-half million. It is doubtful whether Italy ever succeeded in putting a fully equipped army in the field.

It is clear, granted these assumptions are correct in principle, that British steel production during war should be kept at the highest possible level, and the resultant output used with the greatest possible discrimination. Have these two requirements been fulfilled? With regard to the first, Mr. John Brown, Secretary of the British Iron and Steel Trades Confederation, has been quoted as saying that steel output in the United Kingdom has been running at record levels for a considerable time. As it is known that practically the whole of this steel is going into direct and indirect war production (Oliver Lyttelton, in the House of Commons, has stated that less than 7% of our steel supplies are being used for civilian consumption), and using the 1937 peak figure of 13,000,000 tons as our yard-stick, it

would appear that both requirements have been largely fulfilled. In their report, dated November 4, the Select Committee on National Expenditure expressed appreciation of the work done by the Iron and Steel Control, the value of whose achievement in keeping up supplies under difficult conditions they consider worthy of high praise.

The Vulnerability of Plants.

When the war commenced the steel industry was in a highly vulnerable position. Every British steel plant was within bombing range of the enemy. The majority of the works depended upon imported raw materials for at least half their production, and with few exceptions were generally unsuited to the increasing use of native ores, which are in the main low-grade. Pre-war, half the iron production of the country was from imported ores, having approximately twice the iron content of native ores. It was clear, even if they were adapted to do so, their geographical location would present the Ministry of War Transport and the railway executives with many problems. To transport ore from the iron-fields in the Midlands and Lincolnshire, it was calculated, would make an insupportable inroad upon the available rolling stock of the railway companies. At that time the production of native ore was in the neighbourhood of 13,000,000 tons. This ore was for the most part used on the spot by Stewarts and Lloyds, Ltd., at Corby, the United Steel Companies at Appleby-Frodingham, and at Stanton. One of the most clearly established facts of the war is the undoubted success of the railway companies, under the direction of the Ministry of War Transport, in overcoming this major problem. It is believed that iron ore production in this country has been nearly doubled, and it is quite certain that the railway system could not have carried more native ore than has been done. This proved an automatic check upon increased steel production when, as happened in the summer of 1940, we were cut off from the majority of our overseas iron-ore supplies. This position disposed once and for all of any thought there may have been of increasing Britain's steel production to any substantial extent. It was felt by all concerned that the industry would have performed all that could possibly be expected

of it if a good pre-war average output were continuously maintained.

The expected air attack which materialised in the autumn of 1940 passed by without the steelworks suffering any great destruction of capacity. Unparalleled demands during this period for such items as air-raid shelters, constructional steel for war factories, and steel for anti-invasion defences, were satisfactorily fulfilled, some at very short notice. The production of anti-tank defence barriers threw an immense strain upon the country's re-rolling capacity at that time. Apart from these exceptional orders, there were prolonged periods in the early stages of the war when the steel industry found that production was not entirely taken up and the opportunity was seized to lay aside considerable stocks of imported supplies in the pre-Lend-Lease period against the possibility of a more acute position developing later. Stocks were built up to act as a cushion against new and greater demands and possible war damage, and considerable supplies of scrap were also accumulated.

Research Work.

The Iron and Steel Industrial Research Council has performed an onerous task in pooling and co-ordinating the research work, which has been so essential during the war period. Changes in specifications, adaptations of processes, and the production of what, for want of a better word, may be called "new" steels, are all subjects which come within the purview of the Iron and Steel Industrial Research Council. In a recent issue of *METALLURGIA** a detailed picture was given of the peace-time raw materials supply of the steel industry. Without re-capitulating the information given there, it is sufficient to say that we were cut off within the course of a few weeks from four-fifths of our pre-war sources of supply from overseas. Only those within the industry can appreciate the burden which has been laid upon the steelworks, management and men, because of the imperative need to use unsuitable low-grade ores. The use of these alternative raw materials and the constant upgrading of specifications (frequently two entirely contradictory aspects of the same problem) have called for the most intensive research in which all steel firms have pooled their knowledge and experience.

War is a great consumer of alloy steels. Special high-grade alloy steels are needed for armour plate, for armour-piercing shot, for guns, for shells, for aircraft engines, and for the vast number of cutting tools that are needed in the war factories. Alloy steels are made by the admixture of hardening and tempering elements such as chrome, manganese, nickel, vanadium, molybdenum and tungsten in appropriate proportions for different services.

In peace-time there were something like two thousand different grades of alloy steel—depending on the proportion and kind of hardening elements used. In view of the tremendous increase in the demands for special steels—by 1943 demand was three times as great as in 1937, a peak year for British steel output—it was necessary to exercise the strictest economy in the use of all these imported hardening elements. By a painstaking and exhaustive overhaul of specifications by representatives of all the manufacturers, under the chairmanship of the late Dr. Hatfield, the number of

grades was reduced from over two thousand to some fifty-eight major categories. Designers and users of steel were also urged, in the words of the official order, "To consider most carefully the combination of properties, i.e., strength, ductility and notch toughness in making their selection of steels." On the top of this need to economise in hardening elements the maker of high-grade steels was still pursued, right through 1941, by the difficulties inherent in the use of inferior ore and scrap. But with the entry of Japan into the war a further blow was in store.

If it were possible to select any type of steel as being the most important for war production the expert would probably single out high-speed or tool steel. Every war factory using steel as the raw material of its finished weapons must use cutting tools made from tool steel. In peace-time tool steel may contain up to 18% of tungsten, one of the most valuable hardening elements known; and in peace-time 88% of this vital element, used by the British steel industry, came from China and Burma. The loss of these territories, and their supplies to the enemy, was indeed a serious matter for the steel-makers.

Space does not permit of a more detailed reference to the work done by the Research Council. It is sufficient to say that a multitude of problems have been dealt with by the hundred or more bodies consulted by the various research committees. The greatest tribute to the work they have done is the absence of serious complaints from consumers, and the improved efficiency in production processes resulting, for example, in substantial fuel economy.

Organisation of Supplies.

Whilst these fundamental problems of war-time steel production were being met and overcome, the organisation of steel distribution was also being tackled vigorously. On March 19, 1940, the first Distribution of Steel Supplies Scheme was published, followed after a period of six months by a modified and abbreviated version, and a still further degree of simplification was again achieved on July 25, 1941. The Distribution Scheme is based on Iron and Steel Control Orders, of which at the time the 8th and 15th, and now the 32nd, are the most important. These Orders give the Distribution Scheme the force of legal backing, and it is reasonable to state that at a very early stage of the war steel supplies to consumers were firmly controlled. The methods employed are now well known, and the general consensus of opinion is that the Distribution Scheme successfully achieved its object. British steel output and the distribution of supplies, are now linked to the Allied and Dominions' effort. The Dominions and India have substantially increased their production, and the position to-day is that Canada, India, Australia and South Africa, between them, are probably producing six million or more tons of steel per annum.

Black-out Problems

A great problem that faced the steel industry on the outbreak of war was the blacking out of the blast furnaces and coke ovens at the steelworks. Anyone who has travelled through a steel-working district will remember the glow of the blast furnaces, the sudden lighting up of chimney stacks and roofs as a furnace is tapped, the brilliant glare when a coke oven is "pushed," or the spouting flame and cascades of sparks as a

* July 1943

Bessemer converter is "blown." In peace-time it was almost possible to read a newspaper anywhere near the melting shop when a furnace was tapped at night. Now the obscuration of Britain's iron and steel plants is complete. All necessary operations can be carried on right round the clock. The President of the American Iron and Steel Federation, on a mission to Great Britain, regarded this blacking out of steelworks as a major achievement. It was one of the many things that "couldn't be done"—until the steel industry set about doing it. The blackout has thrown a tremendous extra strain on the steelworkers. Even under the best conditions the intense heat necessary for most steelmaking processes makes the work very exacting.

Bomb Production on a "Flow" Basis.

Bomb production has entailed the construction of works devoted entirely to the making of bomb castings, on a "flow" production basis. Just as a motor chassis moves along on the production track with all the units timed to arrive in correct order at the right moment, so each bomb casting moves on bogeys along a narrow-gauge railway that winds through the plant. From the moment the casting is poured, until the completely filled bomb leaves the end of the track, every operation is carefully timed and synchronised so that each operation can be carried out in the correct sequence. One of these works is probably the first great factory of its kind designed for unskilled labour. In advance it was known that only local labour would be available. A careful check-up showed that over 80% of the workers would be women of an unusually high age level. So skilled processes had to be reduced to their ultimate simplicity, and total mechanisation had to be installed to avoid the necessity of handling heavy parts at any stage. Even these formidable difficulties were not, perhaps, the worst of the production experts' troubles. For the loss of ore supplies, which throughout the war

has continued to harass every metallurgist in Britain, made it necessary to use 100% scrap steel in the cupola furnace. Usually castings of the nature required for bomb castings are made from 50% hematite iron and 50% selected steel scrap.

An entirely new method of preheating the metal in a rotary furnace had to be developed before the 100% charge of scrap could yield steel of the requisite quality for casting. All difficulties were surmounted, however, and the foundry swung into its scheduled production— $\times 500$ -lb. bombs every hour, ready for filling: but war is the great forcing house of technological developments. Within a few months of the opening of the plant an improved type of bomb was designed requiring a steel casting of only one-half the thickness of the original specifications. It is the task of the production expert to show equal ingenuity in his particular field in adjusting processes and schedules to new requirements. In this case, in a very short time, the necessary modifications in foundry processes were introduced and the new type of castings began to flow on to the production line at the rate of two a minute.

Price Stabilisation.

In November, 1940, the price of steel was stabilised. From the beginning of the war the policy of fixed standard prices as the basis of the Iron and Steel Control's price system had been applied to a wide range of raw material and processing trades. This system was steadily extended until to-day prices for many thousands of different specifications, sizes and shapes of steel have been fixed.

All in all, the foregoing account of some of the steel industry's war effort, necessarily circumscribed because of security considerations which do not permit of the publication of vital statistics and other important relevant circumstances, provides a not unsatisfactory picture of our key industry. The full story will have to wait until after the war.

Alloy and Special Steels

Peacetime Developments and Wartime Applications

By J. W. Donaldson, D.Sc.

PREVIOUS to the war, as a result of the experimental and research work which had been carried out by the steel industry, a large number of fresh advances had been made, and many of them related to special and alloy steels. The use of alloy steels in all industries had increased considerably and were continuing to increase, not only for natural and general engineering purposes, but also for parts to resist corrosion and for parts where heat-resistant material was of importance. Considerable developments had also taken place in steel treatments and steel processes, and in these developments alloy and special steels had played a prominent part.

Stainless Steels

In this pre-war progress the development of stainless steel was of major importance. Stainless steel of the 18/8 variety had been stabilised against intergranular corrosion, not only by the addition of molybdenum,

tungsten and titanium, but also by the rarer elements tantalum and columbium. A steel of the 16/1 type had been developed which did not resist corrosion quite so effectively, but had the advantage that it could be machined with much greater ease. In this steel the mechanical properties were found to be maintained, which added to its useful value as the development of free machining stainless steels by increasing the sulphur content or adding selenium or zirconium reduced the mechanical properties. More promising results were obtained by the addition of 0.15 to 0.35% of lead. A 29/9 chromium-nickel steel with good casting properties and a high resistance to intergranular corrosion had also been developed, and in Germany and Russia, owing to the nickel shortage, manganese stainless steels had been produced in which manganese replaced the nickel content of the ordinary 18/8 variety.

Among other developments in stainless steel had been the production of stainless steel wire on a commercial

basis and the introduction of a welding 18/8 stainless steel with a carbon content of 0.08% maximum. Nitrogen was also found to be beneficial as an alloy in chromium and chromium-nickel stainless steels by refining the crystalline structure of the steels and making them more ductile, tougher, and more easily capable of being deep-drawn or stamped. Stainless steels containing nitrogen were found to be capable of withstanding very heavy wear without cracking and could be machined with much greater ease than the standard type. Their mechanical properties were good so long as the carbon was kept low and they were very resistant to corrosion.

Apart from the stainless steels, a wide range of new steels were also developed, in the years immediately prior to the war, with corrosion-resisting properties intermediate between those of the stainless steels and steels with low corrosion resistance, and also having good resistance properties to hot gases and acids. These steels included low carbon steels containing 4 to 6% of chromium with or without molybdenum or tungsten, 9% chromium steel containing molybdenum, 2% chromium steel containing vanadium and molybdenum, and 2% chromium steel containing columbium. Columbium when added to the 4 to 6% chromium steels was also found to have a stabilising effect and to increase their creep resistance.

Structural Steels

A number of alloy steels were also developed for general engineering purposes, and in some cases were replacing nickel and nickel-chromium steels. These steels included the nickel-chromium-molybdenum steels and the nickel-chromium-silicon steels having tensile strengths of over 60 tons per sq. in. Low alloy steels containing manganese, chromium and vanadium were also found to be very suitable for parts subjected to medium stresses and manganese-molybdenum steels gave a wide range of alloy steels for engineering parts. Other low alloy steels developed were those for corrosion resistance containing copper, nickel and molybdenum, copper and molybdenum, and chromium and copper. Another alloy steel capable of withstanding high-temperature conditions was one containing 35% chromium, 7% aluminium.

Before the war, the use of alloy steel castings was being increased. Vanadium added to carbon steel was found to increase its toughness and hardness and to give castings containing a much better grain structure. Promising results were also being obtained with more complex vanadium alloy steels which could be easily heat-treated. For highly alloyed steel castings centrifugal casting methods were being developed.

The discovery of the high-speed tool steels containing chromium with their increased cutting properties led to many investigations to improve on such steels. Not only were percentages of existing elements, including carbon, in high-speed steels increased, but rare elements, such as tantalum and uranium, were also added. Little progress, however, was made. In the United States, as the result of long and careful investigation, molybdenum high-speed tool steels were developed in which four-fifths of the tungsten in the normal high-speed tool steels were replaced by molybdenum. Such steels were found to give in some machining processes results quite the equivalent of those obtained by standard tungsten and tungsten-cobalt types.

Processing and Treatment

In the processing of steel involving the use of special and alloy steels, advances were also being made in nitriding, surface-hardening, hard-surfacing and cladding. In addition to the carbon-chromium-aluminium steel generally used for nitriding (Nitralloy), certain aluminium-free steels had been developed and nitrogen-hardening had been extended to austenitic and stainless steels. In the application of surface-hardening to alloy steels most satisfactory results were obtained with 1% chromium steel, nickel-chromium steels (1.5% nickel, 1% chromium), and nickel-chromium-molybdenum steels containing 3.5% nickel, 1% chromium, and 0.3% molybdenum. Hard-surfacing was carried out

TABLE I.—"PERMITTED ALLOY STEELS."

B.S. En. No.	Type of Steel.
8	40 carbon (1% nickel maximum optional)
11	60 carbon-chromium
12	40 carbon (1% nickel maximum optional)
13	Manganese-nickel-molybdenum
16	Manganese-molybdenum
17	Manganese-molybdenum (higher molybdenum)
18	1% chromium
19	1% chromium-molybdenum
24	1% nickel-chromium (molybdenum optional)
25	2% nickel-chromium-molybdenum (medium carbon)
26	2% nickel-chromium-molybdenum (higher carbon)
30	4% nickel-chromium
31	1% carbon-chromium
33	3% nickel case-hardening
34	2% nickel-molybdenum case-hardening
35	2% nickel-molybdenum (higher carbon) case-hardening
36	3% nickel-chromium case-hardening
39	4% nickel-chromium case-hardening
40	5% chromium-molybdenum
41	1% chromium-aluminium-molybdenum
48	1% chromium
50	Chromium-titanium
51	3% nickel
52	Silicon-chromium
53	Silicon-chromium
54	Nickel-chromium-tungsten
55	Chromium-nickel-tungsten
56	Chromium rust-resisting
56M	Chromium rust-resisting (low carbon)
56Al	Chromium rust-resisting (low carbon)
56AM	Chromium rust-resisting (low carbon)
57	Chromium-nickel rust-resisting (high tensile)
58	Austenitic chromium-nickel rust- and acid-resisting
58A	Austenitic chromium-nickel rust- and acid-resisting
100	Low alloy (heat-treated bars for machining)

successfully, both with low-alloy and high-alloy steels and the cladding of steel was developed by the welding of nickel-steel to other steels. A new method had also been developed for the production of austenitic nickel-chromium steel coatings, and for nickel-steel coatings by which a very thin film of pure iron was electrolytically deposited between the cladding material and the backing material and then welded together under pressure.

War-time Restrictions

The advent of the war produced a marked change with regard to alloy and special steels. Owing to the demands on steel of all types for armaments, research and development was greatly curtailed and the production of steels already established and in use had to be reviewed in the light of the raw materials available for their manufacture. Metals such as nickel, chromium, tungsten, molybdenum and vanadium used in the production of alloy steels were chiefly obtained from overseas and therefore because of strategic importance being no longer available in quantities sufficient to meet the demands of the alloy steels being produced. The whole field of alloy steel-making had therefore to be considered and a substantial reduction made in the number of alloy steels used. The utilisation of steel scrap containing low alloy additions had also to be considered and the production

of low-alloy steels from such scrap investigated. In this work the large number of alloy steels developed previous to the war offered a large variety of alloys to make such a selection from.

This work of rationalisation and of scrap utilisation with the object of alloy conservation was carried out by the Technical Advisory Committee of the Special and Alloy Steels Committee of the Steel Control of the Ministry of Supply, composed of steel-makers, representatives of the services and the British Standards Institution, and resulted in a number of specifications and schedules being used by the British Standards Institution. The first of these, B.S. 970, issued in 1941, contained particulars of 58 steels, the En steels, of which 43 were alloy steels. A companion Schedule, B.S. 971,

respectively, and making use of the alloy constituents of steel scrap. Two specifications for carbon-manganese case-hardening steels were also issued. In 1943, a new direction based on B.S. 970, 1942, was also issued, setting forth certain restrictions with regard to alloy steels.

Permitted Alloy Steels

From these various schedules in which wrought steels in the form of bars, billets, light forgings, and stampings, up to 6 in. ruling section are rationalised, certain alloy steels are available for selection for given purposes and cover the whole range of tensile strengths, from 38 tons per sq. in. upwards. These alloy steels include three carbon-manganese steels, a manganese-nickel-molybdenum steel, two manganese-molybdenum steels, a chromium steel, a chromium-molybdenum steel, three nickel-chromium-molybdenum steels, and a carbon-chromium steel. Special steels include a chromium-nickel steel, silicon-chromium steels, chromium-nickel tungsten steels, chromium rust-resisting steels, chromium-nickel rust-resisting steels and austenitic chromium-nickel rust- and acid-resisting steels. In addition, there are also five alloy case-hardening steels and a nitriding steel available. In Table I are given the only alloy wrought steels, which may now be made for parts up to 6 in. ruling section. No restriction is placed on steels containing less than 0.40% of chromium or nickel, 0.10% of molybdenum, tungsten or vanadium, or 10% of manganese.

The three carbon-manganese steels contain 1.3 to 1.8% manganese and varying amounts of carbon. The lower carbon steel has a minimum tensile strength of 38 tons per sq. in., and the higher carbon steel tensile ranges of from 40 to 50 to 50 to 60 tons per sq. in. according to the section. The former steel is widely used for welded and riveted structures, and the latter steel for axles, shafts and heat-treated gun parts, and as a substitute for low-nickel steel for large (4 in.) sections. The third manganese steel is of welding quality and is used for general welded structures.

The manganese-nickel-molybdenum steel, the manganese-molybdenum steels, the 1% chromium steel, and the 1% chromium-molybdenum steel are all high-tensile steels, giving in a 1½ in. section after suitable oil-hardening and tempering, minimum tensile strengths ranging from 40 to 45 tons per sq. in. The manganese-nickel-molybdenum steel is a general purpose economical alloy steel, the manganese-molybdenum steels are used to replace 3 and 3½% nickel steels in small and large sections, respectively, and the chromium-molybdenum steel to replace nickel and nickel-chromium steels for many parts. The 1% chromium steel is suitable for gears, connecting rods and other automobile parts.

The three nickel-chromium-molybdenum steels, after suitable oil-hardening and tempering, have minimum tensile strengths ranging from 70 to 100 tons per sq. in. in 1½ in. sections, and are used for highly stressed transmission parts and in their lower tensile range for replacing 3% nickel-chromium steel. The 4½% nickel-chromium steel which on oil- or air-hardening has a minimum tensile strength of 100 tons per sq. in., is also used for highly stressed gears and other transmission components and for parts requiring freedom from distortion in heat-treatment. The 1% carbon-chromium steel is suitable for ball and roller bearings having a diamond pyramid hardness of 800 to 950 after suitable

TABLE II.—CASE-HARDENING STEELS.

B.S. En. No.	Type.	Specified Core Properties.	
		Ultimate Tensile Strength, Tons/sq. in.	Impact Ft./lb.
32	Carbon case-hardening	32	40
101	Carbon-manganese case-hardening ..	40	40
102	Carbon-manganese case-hardening ...	40	30
33	3% nickel case-hardening	45	40
34	2% nickel-molybdenum (lower C.) ..	45	40
35	2% nickel-molybdenum (higher C.) ..	55	25
36	3% nickel-chromium	55-65	35-30
39	4½% nickel-chromium	85	25

TABLE III.—HEAT-TREATED LOW-ALLOY STEEL BARS FOR MACHINING (B.S. EN. 100).

CHEMICAL COMPOSITION.		MECHANICAL PROPERTIES.				
Carbon	Not less than 0.35% and not more than 0.45%	R.	T.	U.	V.	
Silicon	Not more than 0.50%	6 in.	4 in.	2½ in.	1½ in.	1½ in.
Manganese	Not less than 1.2% and not more than 1.5%	45	50	55	60	65
Nickel	Not less than 0.5% and not more than 1.0%	34	38	44	48	52
Chromium	Not less than 0.3% and not more than 0.6%	22	20	18	17	16
Molybdenum	Not less than 0.15% and not more than 0.25%	40	40	40	35	35
Sulphur	Not more than 0.05%	192/260	217/203	241/311	262/341	285/352
Phosphorus	Not more than 0.05%					
Limiting ruling section up to						
Ultimate tensile stress, tons						
per sq. in., not less than...						
Yield point, tons per sq. in.,						
not less than...						
Elongation %, not less than						
Isod impact value, ft./lb.,						
not less than...						
Brinell hardness						

was issued at the same time with the object of facilitating the supply of carbon and alloy steels for war purposes and contained 33 steel specifications of which 24 were for alloy steels. In this T.A.C. schedule, certain steels are recommended as the most suitable for certain purposes, and these together with the alternatives given provide the basis of the En steels contained in the first schedule.

In 1942, a further schedule of service steels, B.S./S.T.A. 5, for armament and vehicle manufacture was issued, being prefaced as a statement of the general service requirements for engineering steels necessary to co-ordinate and supply the material aspect of wartime manufacture. This schedule was stated to be an explanatory one of requirements based on the revised B.S. 970, 1942, and also took into account the Direction of the Controller, B.S. 970A, 1942, which limited the available types of alloy steels and enforced the economical use of alloy elements. During the present year two amendments were issued to the B.S. 970, 1942, schedule, giving two additional specifications for heat-treated low alloy steel and low nickel-chromium-molybdenum steel

treatment. Some of these alloy steels are also available in the form of seamless tubes as well as in the form of bars, billets, etc.

With regard to special alloy steels, the 1% chromium steel, oil-hardened and tempered to give a Brinell hardness of 341 to 429, and the chromium-vanadium containing 1 to 1.5% chromium and 0.15% vanadium are suitable for valve springs. For valves, five special steels are available. These include a 3% nickel steel; two silicon-chromium steels, one containing 3 to 3.75% silicon and 7.5 to 9.5% chromium and the other 1.4 to 1.7% silicon and 5.75 to 6.75% chromium, the former having a Brinell hardness of 255 to 293, and the latter a hardness of 235 to 258; a high nickel-chromium-tungsten steel, 10% nickel, 12 to 16% chromium and 2 to 4% tungsten, and a high chromium-nickel-tungsten steel, 17% chromium, 6 to 12% nickel, 2 to 4% tungsten.

TABLE IV.—LOW-NICKEL CHROMIUM-MOLYBDENUM STEEL
(B.S. EN. 119).

CHEMICAL COMPOSITION.						
Carbon	Not less than 0.35%	and not more than 0.45%				
Silicon	Not less than 0.10%	and not more than 0.35%				
Manganese	Not less than 0.40%	and not more than 0.80%				
Nickel	Not less than 1.2%	and not more than 1.6%				
Chromium	Not less than 0.9%	and not more than 1.4%				
Molybdenum	Not less than 0.10%	and not more than 0.2%				
Sulphur	Not more than 0.06%					
Phosphorus	Not more than 0.05%					
MECHANICAL PROPERTIES.						
	R. 6 in.	S. 4 in.	T. 4 in.	U. 2½ in.	V. 1½ in.	W. 1½ in.
Limiting ruling section up to ultimate tensile stress, tons per sq. in., not less than..	45	50	55	60	65	70
Yield point, tons per sq. in., not less than.....	34	38	44	48	52	58
Elongation %., not less than	22	20	18	17	16	15
Isod impact value, ft./lb., not less than.....	40	40	40	35	35	30
Brinell hardness	192/269	217/293	241/311	262/341	285/352	302/375

Corrosion rust-resisting steels allowed, contain 12% chromium and 0.15 to 0.35% carbon, under 0.15% carbon and under 0.12% carbon. The latter steel is specified for use as turbine blade material. In another variety suitable for free machining, containing less than 0.15% carbon and 12% chromium, sulphur may be present up to 0.75%, or lead up to 0.35%, or one or more of the elements selenium, zirconium, or nickel may be added to a total amount of not more than 1%. High tensile chromium-nickel rust-resisting steel, containing 15.5 to 20% chromium, 1% nickel, and having a minimum tensile strength of 55 tons per sq. in., is also available. Two austenitic chromium-nickel rust and acid-resisting steels are specified to contain 6 to 20% nickel, 12% chromium, or 8 to 10% nickel, 16 to 20% chromium respectively. Tungsten, titanium, molybdenum, copper, vanadium, columbium or tantalum may also be present. Some of these special alloy steels may also be obtained in the form of sheets, strip, wire and tubes, as well as in the form of bars, billets and forgings.

In Table II are given the only permitted alloy steels for case-hardening, together with a carbon case-hardening steel and two new carbon-manganese case-hardening steels which have physical properties for which only alloy steel was previously obtainable. These two latter steels contain 0.12 to 0.18% carbon, and 1.25 to 1.75% manganese, and the second is a free-machining steel. The two nickel-molybdenum steels are used for gears and other transmission components and for gears, shafts, pinions and other case-hardened components respectively, and the former steel can be used generally to replace 3% nickel-chromium case-hardening steel and

the latter to replace 5% nickel-chromium case-hardening steel for many purposes. The two nickel-chromium case-hardening steels are used for transmission parts and for small arms mechanism components, and for heavy duty gears and heavy roller bearings respectively.

Low Alloy Steels

To utilise to the greatest advantage the alloy content of steel scrap, two specifications have been prepared for low alloy steels. The first is for heat-treated low alloy steel bars for machining, suitable for tensile ranges from 45 to 55 to 65 to 75 tons per sq. in. according to the size of the part. The composition and mechanical properties of the various ruling sections of this steel are given in Table III. Heat-treatments consist of hardening in oil or water from 830° to 860° C. and tempering at a suitable temperature not less than 530° C.

The second is for low nickel-chromium-molybdenum steel in the form of bars and billets for forgings, forgings and drop forgings and bars for machining, suitable for tensile ranges of 45 to 55 to 65 to 75 tons per sq. in. Heat-treatment consists in oil-hardening from a temperature of 830° to 860° C., and tempering at a suitable temperature not exceeding 660° C. In Table IV are given the composition of this steel and its mechanical properties for the various ruling sections up to 6 in. The material covered by this specification is capable of meeting the test requirements of the En specification for the two manganese-molybdenum steels and the 1% chromium-molybdenum steel.

Tool Steels

Before the war and during the first two years of the war, high-speed tool steels used in this country contained 14, 18 or 22% tungsten or were tungsten-cobalt steel, also having a high tungsten content. In the United States a series of molybdenum-low tungsten steels had been developed and were being used successfully. With the loss of the main sources of tungsten early in 1942, it became necessary to conserve this element and substitute steels of the American type were recommended by the Iron and Steel Control to replace high-tungsten high-speed steels. Standard high-tungsten high-speed tool steel and high-speed steel containing cobalt were only allowed to be manufactured under licence when it was proved that substitute steels were not suitable.

Substitute steels 66 and 94 consist of known and proved compositions, the former containing 5 to 6% molybdenum, 5.5 to 6.5% tungsten, 4 to 5% chromium, 1.25 to 1.5% vanadium, and the latter 8.5 to 9% molybdenum, 3.5 to 4.5% tungsten, 3.5 to 4.5% chromium, and 1.25 to 1.5% vanadium. These steels can be handled in a similar manner to that adapted for standard high-speed tool steels, provided it is recognised that they are more susceptible to decarburisation, that lower temperatures must be used during forging and that lower hardening and tempering temperatures are necessary.

In a more recent direction of the Ministry of Supply, Iron and Steel Control, the use of substitute steel 66, which was generally used, has been cancelled, and a new high-speed tool steel, molybdenum 46, substituted. This steel contains 3.9 to 4.4% molybdenum, 5 to 6% tungsten, 4 to 5% chromium, and 1.4 to 1.6% vanadium, is forged and handled somewhat similar to the 66 steels, and if care is taken in its treatment gives an equal performance to that steel.

Further Developments in the Production and Technology of Magnesium and its Alloys

By F. A. Fox, M.Sc., and G. Goddard, M.Eng.

Expansion in the use of magnesium in recent years has been phenomenal, due to growing demands in aircraft and munitions industries. This has encouraged rapid progress in technique to apply this metal and its alloys to advantage. Developments in production are reviewed, and attention directed to British and American magnesium alloy practices. The more important aspects of technological developments are outlined and a brief reference made to some present applications of magnesium alloys.

Production

DEVELOPMENTS in the manufacture and technology of metals and alloys always progress at a rapid rate in times of war, and those pertaining to the magnesium industry under present conditions are of outstanding interest. The growing demands for magnesium alloys in the aircraft and munitions industries have been responsible for an extraordinary expansion in magnesium metal production, particularly in the United States of America. Little precise information is available on the development of magnesium metal production in Great Britain, but the considerable expansion of the American industry has been much publicised. The following U.S. production rates have been quoted :—¹

	Tons.
1939	3,040
1940	5,680
1941	13,600
1942	34,700
1943	Scheduled at 350,000 ²

and the estimated present-time outputs of other countries have been given³ as :—

	Tons/Annum.
Germany	50,000
Japan	14,000
Great Britain	36,000

The first large-scale expansion in the U.S.A., which was initiated in the period prior to the entrance of the U.S. into the war, was subsidised by the British Government. Since December, 1941, however, development in that country has been so rapid that, as can be seen from the figures given above, the U.S. now leads the world in magnesium production. Plants of enormous proportions, operating both electrolytic and thermal reduction processes, have been erected.

The plant of Basic Magnesium Inc., near Las Vegas, Nevada, the largest magnesium plant in the world with a present output in excess of 50,000 tons per annum, produces magnesium by the electrolysis of fused anhydrous magnesium chloride in the M.E.L. cell. British technicians, from Magnesium Elektron Ltd., were responsible for guiding the design and erection and for starting up this enormous plant. Nearly fifty members of the staff of Basic Magnesium Incorporated were trained at the Clifton Junction works of Magnesium Elektron Ltd.

The Dow Chemical Co., the pioneers of magnesium metal production in the U.S.A., are now operating several large electrolytic plants utilising the Dow cell and magnesium chloride processed from sea-water and underground brines, and are stated³ to be producing one-third of the U.S. output.

Thermal processes, the Hansgier carbo-thermal reduction process and the much-publicised Pidgeon ferro-silicon process, also contribute to the total scheduled output of magnesium.

The British Empire also is assisting materially in the Allied output of metal; in Canada and Australia magnesium is produced by thermal reduction processes, the Pidgeon ferro-silicon process in the former country and the carbide reduction process in the latter.

The considerable Allied output of magnesium alloys, consequent upon the above outlined developments of magnesium metal manufacture, is devoted exclusively to the needs of war both in engineering applications and in the munitions industry. In Great Britain, up to recent times, the priority demands of magnesium and magnesium alloys in the munitions industry were such that there was a shortage of metal for aircraft engineering and other applications, and, in fact, replacement of some magnesium alloy parts by aluminium alloys became necessary in aircraft construction. On this account technological developments and the use of magnesium alloys in new fields of application were retarded somewhat in this country. The proximity of peak capacity in magnesium metal production has, however, brought about a change in policy and new applications of magnesium alloys, particularly in aircraft construction, are receiving consideration; it is to be expected that the near future will see innovations in this direction.

In the U.S.A. the general position was somewhat different—America's non-belligerent policy up to the end of 1941 accompanied by the rapid domestic expansion of magnesium manufacture, fostered development of alloy technology to a greater extent than in Great Britain; this is reflected in the technical press.

British and American Magnesium Alloy Practices

Anglo-American technical interchange has primarily focused attention on current American and British magnesium alloy practices. The independent progress of the industry in the two countries has resulted in some divergences of practice which are worthy of comment.

¹ "Automotive and Aviation Industries." (U.S.A.) March, 1943, 88 (6), 77.

² E. D. Wilson, *Metals and Alloys*, March, 1942, 15 (3).

³ H. I. Brame, *Iron Age*, April 15 1943, 151 (16), 64.

The salient differences appear to be best examined mainly by a comparison of the existing magnesium alloy specifications of both countries. British (D.T.D.) and American specification requirements are given in Tables I and II; it must be noted, however, that the tabulated chemical and mechanical property requirements do not embrace the full range of existing specifications, but include mainly only those which are relevant to the discussion that follows.

Wrought Alloys

Chemical Composition.—Generally, the wrought alloys in common usage in Britain and in the U.S.A. are almost identical in respect of major alloying elements, but important differences exist as regards minor impurities, particularly the iron limits. The U.S. limit, where any is given, is 0.005%—a very low figure which may be difficult of attainment in the ordinary foundry. It seems that the maximum iron requirements in some U.S. specifications have been influenced by fairly recent publications,^{16, 17} which have indicated that the corrosion rates of some binary magnesium-aluminium alloys are decreased when their iron content is low. In the more complex commercial alloys—i.e., alloys to which manganese is added to enhance corrosion resistance, the imposition of such low iron content is considered by British technicians to be probably unjustifiable, and it is an interesting fact that the American technical press contains no reference to the relative corrosion rates of high- and normal-purity commercial alloys. The whole question of iron contamination of magnesium alloys and its practical effects on the corrosion of the actual alloys, protected and unprotected, is somewhat obscure, although research work on this subject is progressing.

Mechanical Properties.—Comparison of the U.S. and existing British specifications for wrought magnesium alloy products indicate a close similarity in minimum mechanical property requirements except in the case of Elektron AM. 503 sheet and Elektron A. 8 and Elektron AZM type forgings, for which the U.S. minimum mechanical property requirements are higher than those of the D.T.D. requirements.

Casting Alloys

Chemical Composition.—In contrast to the wrought alloy practice, casting alloy practices in Britain and in the U.S.A. show a wide divergence. The widely used British casting alloys of the Elektron A. 8 and Elektron AZ. 91 types so far appear to hold little favour in the U.S.A., where alloys containing 6% aluminium, 3% zinc (Elektron AZG type, such as Dowmetal H and AM. 265) and 9½% aluminium, 2% zinc (Dowmetal C, AM. 260) respectively, with the usual manganese additions, are in common usage.

The main claims for the adoption of an alloy of Dowmetal H composition in the U.S.A. are its superior test-bar mechanical properties and its slightly superior corrosion resistance. This alloy, however, finds little usage in Britain mainly because experience and laboratory radiographic evidence⁴ has shown that it is much more prone to microporosity than either Elektron A. 8 or Elektron AZ. 91; another contributory factor is the experience of some Elektron casters in Britain that the 6% aluminium, 3% zinc alloy tends to hot-shortness. This, as with its tendency to heavy microporosity, is associated with its wide solidification range.

⁴ L. Lasch, *Magnesium Review and Abstracts*, January 1943, III (2), 42–47.

TABLE I.—BRITISH AND AMERICAN

Form	Alloy Designations.	Source and Number
Tubing	Elektron AZM....	British D.T.D. 548
	Dowmetal J-1....	U.S. Navy No. 44T35 Alloy 8
	AM. 57S	U.S. Army Air Force No. 11832
Extrusions	Elektron AZM....	British D.T.D. 259
	Dowmetal J-1....	U.S. Navy Aeronautical M314C Alloy 8
	AM. 57S	U.S. Army Air Force 11335
		A.S.T.M. B. 107-41T. Alloy 8X
	Elektron AM. 503	British D.T.D. 142
	Dowmetal M	U.S. Navy Aeronautical M314C Alloy 11
Sheet	AM. 3S	U.S. Army Air Force 11336
		A.S.T.M. B. 107-41T Alloy 11
	Elektron AM. 503	British D.T.D. 118
	Dowmetal M	U.S. Navy 47.M.2. Alloy 11
	AM. 3S	U.S. Army Air Force 11339
		A.S.T.M. B. 90-41T. Alloy 11
	Elektron AZM....	British D.T.D. 120A
	Dowmetal J-1....	U.S. Navy 47.M.2. Alloy 8
	AM. 57S	U.S. Army Air Force 11338
		A.S.T.M. B. 90-41T. Alloy 8X
	Elektron A. 4	British D.T.D. 120A
	Dowmetal FS-1 ..	U.S. Navy 47 M.2. Alloy 18
Forgings	AM. C52S	U.S. Army Air Force 11340
		A.S.T.M. B. 90-41T. Alloy 18X
	Elektron AZM....	British D.T.D. 88B
	Dowmetal J-1....	U.S. Navy 46.M.13 Alloy 8
	AM. 57S	U.S. Army Air Force 11345
		A.S.T.M. B-91-41T Alloy 8X
	Elektron A. 8	British D.T.D. 88B
	Dowmetal 0-1 ..	U.S. Navy 46.M.13. Alloy 9
	AM. C58S	U.S. Army Air Force 11321A
		A.S.T.M. B. 91-41T. Alloy 9X
	Elektron AM. 503	U.S. Navy 46.M.13. Alloy 11
	Dowmetal M	(No British D.T.D. exists)

With regard to the considerations of enhanced corrosion resistance due to the presence of a high zinc content, research in this country has indicated that the beneficial effects of zinc are slight or even non-existent for some conditions.

No British alloy of composition comparable to Dowmetal C or AM. 260 (Mg + 9½% aluminium, 2% zinc, 0.3% manganese) exists. U.S. technicians have, however, stated that alloys of this type are more suitable for pressure tight applications than alloys of the Dow H (Elektron AZG) type.

It will be seen that for the casting alloys the impurity limits in the D.T.D. specifications are higher than are permitted in the U.S. specifications. In spite of the higher permissible impurity limits in the British specifications, in general the total impurity contents of British and American casting alloys are of a similar order. It is of interest to note that the U.S. specifications for casting alloys do not quote an iron figure, although it appears regularly in the U.S. wrought alloys specifications.

Mechanical Properties.—The minimum mechanical properties requirements of British and U.S. specifications call for no special comment.

Technological Developments

Under present conditions the publication of the results of research work is necessarily considerably curtailed. For this reason the following sections which are intended to outline the more important published information on the metallurgy of magnesium and its alloys can give only a skeleton picture of developments of recent times.

SPECIFICATIONS FOR WROUGHT MAGNESIUM ALLOYS.

Current Specifications and Specification Requirements.

Chemical Analysis, Maximum or Range of Values of Elements Specified.									Minimum Tensile Property Requirements.		
Al.	Zn.	Mn.	Cu.	Si.	Fe.	Ni.	T.I. or T.O.I. ^a	Mg.	Proof Stress, T.S.L. [†]	Ultimate Stress, T.S.L.	% Elongation on 4√s.
7.5 max. 5.8-7.2	1.5 max. 0.4-1.5	1.0 max. 0.15 min.	(Cu + Si + Fe, 1.5 max.) 0.05	0.3	0.005	0.005	0.3	Rem. Rem.	— 7.6	16.0 16.1	7.5 7.0
11. max. 5.8-7.2	1.5 max. 0.4-1.5	1.0 max. 0.15 min.	—	—	—	—	1.5	Rem. Rem.	— 2 in. 2 in. 11.0 9.0 Rods. Shapes. 11.6 10.3	— 2 in. 2 in. 17.0 14.0 Rods. Shapes. 17.8 17.0	— 2 in. 2 in. 10.0 5.0 Rods. Shapes. 12.0 10.0
0.2 — —	0.2 — —	2.5 max. 1.20 min. 1.20 min.	0.2 0.05 0.05	0.4 0.3 0.3	— — —	— 0.01 0.03	0.5 0.3 0.3	Rem. Rem. Rem.	8.0 Rods. Shapes. 8.9 7.6	15.0 Rods. Shapes. 14.3 14.3	2.0 Rods. Shapes. 3.0 3.0
0.2 — —	0.2 — —	2.5 max. 1.20 min. 1.20 min.	0.2 0.05 0.05	0.4 0.3 0.3	— — —	— 0.01 0.03	0.5 0.3 0.3	Rem. Rem. Rem.	— — —	11.0 12.5 12.5	— 12.0 12.0
9.0 max. 5.8-7.2	1.5 max. 0.4-1.5	1.0 max. 0.15 min.	0.3 0.05	0.4 0.3	— 0.005	— 0.005	— 0.3	Rem. Rem.	7.0 —	16.0 16.5	10.0 8.0
9.0 max. 2.5-3.5 2.4-3.5 2.4-3.0	1.5 max. 0.7-1.3 0.7-1.3 0.7-1.3	1.0 max. 0.2 min. 0.2 min. 0.2 min.	0.3 0.05 0.05 0.05	0.4 0.3 0.3 0.3	— — 0.005 0.005	— 0.01 0.005 0.005	— 0.3 0.3 0.3	Rem. Rem. Rem. Rem.	7.0 — — —	16.0 14.3 14.3 14.3	10.0 12.0 12.0 12.0
11.0 max. 5.8-7.2	1.5 max. 0.4-1.5	1.0 max. 0.15 min.	— 0.05	— 0.3	— 0.005	— 0.005	1.5 max. 0.3	Rem. Rem.	8.0 9.8	15.0 17.0	5.0 6.0
11.0 max. 7.8-9.2 7.8-9.2 7.8-9.2	1.5 max. 0.8 max. 0.2-0.8 0.2-0.8	1.0 max. 0.15 min. 0.15 min. 0.15 min.	— 0.05 0.05 0.05	— 0.3 0.3 0.3	— 0.005 0.005 0.005	— 0.005 0.005 0.005	1.5 max. 0.3 0.3 0.3	Rem. Rem. Rem. Rem.	8.0 10.7 11.7 10.7	15.0 18.7 18.7 18.7	5.0 5.0 5.0 5.0
—	—	1.20 min.	0.05	0.3	—	0.01	0.3	Rem.	5.3	12.9	2.0

^a T.I. = Total impurities British specifications; T.O.I. = Total other impurities U.S. specifications.[†] Proof stress at 0.1% permanent set for British specifications and 0.2% for U.S. specifications.[‡] — 2 in. = Bars up to and including 2 in. diameter. 2 in. = Bars greater than 2 in. diameter.[§] In A.S.T.M. specifications R = Rods up to 1½ in. diameter or square only.

The Metallography of Magnesium Alloys

Several recent publications have contributed considerably to the knowledge of the metallography of magnesium and its alloys. Two publications of a general type, one a book from Germany⁵ and one from the U.S.A.⁶ which consider the metallographic characteristics of the commercial casting and wrought magnesium alloys in some detail, and a British publication⁷ describing the specialised metallographic technique for magnesium alloys, contain information of value to metallurgists and other technicians.

The German investigators Fahrenhorst and Bulian have reported an extension of their researches on the rather obscure question of the occurrence of iron in pure magnesium and in magnesium-manganese alloys. An earlier paper⁸ reported that iron exists in solution in molten magnesium and that a microscopically visible iron-rich phase appears in the solid metal. A later paper⁹ has shown that the iron-rich phase exists in various forms which are dependent on solidification conditions of the melt. Leaf-shaped and sextuple starlet dendrites were found in metal from the bottom

of crucibles which had been rapidly cooled, the dendrites being larger and more numerous in the melts taken to the higher temperatures. Slowly cooled metal showed massive crystals of iron-rich phase, which assumed a eutectic form at very slow cooling rates. Iron-rich crystals were separated from the magnesium matrix with 10-20% ammonium chloride solution and were found to consist of iron containing 2% by weight of magnesium in solid solution. No evidence of a magnesium-iron compound or a peritectic was found. The investigators have related the

crystallography of the precipitated iron-rich phase to the rate of cooling of the melt and the γ - α iron transition, in the case of γ iron the crystals show a preferred rhombic-octahedral form and for α iron an octahedral form.

An appeal for the adoption of a standard nomenclature for magnesium alloy microstructures has been made in a paper by Fisher¹⁰ which puts forward a system of nomenclature based on the structural terms of steel metallography and which covers the principal microstructures observed in the heat-treated magnesium-base aluminium containing alloys.

Recent work¹¹ in the laboratories of Magnesium Elektron Ltd., has contributed to the knowledge of the effects of precipitation treatments of binary magnesium-aluminium alloys. Metallographic examinations of a range of binary magnesium-aluminium alloys in the solution-treated and precipitated states have distinguished four main forms of beta precipitation:—

Precipitate growing from the grain boundaries.

Precipitate forming within the grains.

A mosaic form of precipitate.

A coarse spheroidised precipitate.

These four types of precipitate are illustrated in Figs. 1 to 4 respectively.*

10 A. Fisher. *Magnesium Review and Abstracts* January 1943 III(2) 31-38.

11 F. A. Fox and E. Lardner. *J. Inst. Metals*, September, 1943, 69 (9), 372-390.

* From *J. Inst. Metals*, September, 1943, 69 (9), Plate xxxi, figure 8, Plate xxxii, figure 10, Plate xxxiii, figures 18 and 16 respectively.

5 W. Bulian and E. Fahrenhorst. "Metallographie des Magnesiums unter seiner Technischen Legierungen," Berlin, 1941.

6 J. B. Hess and P. F. George. A paper presented before the 24th Annual Convention of the American Society for Metals, October, 1942, and printed in A.S.M. Bulletin No. DM-59; reprinted in *Metal Industry*, February 19, 1943, 62 (8), 114-116; and February 26, 1943, 62 (9), 136-138.

7 F. A. Fox and H. T. Hall. *Magnesium Review and Abstracts*, April, 1943, III (3), 70-76.

8 W. Bulian and E. Fahrenhorst. *Z. Metall.*, January, 1941, 33 (1), 31-34.

9 W. Bulian and E. Fahrenhorst. *Z. Metall.*, July, 1942, 34 (7), 166-170.

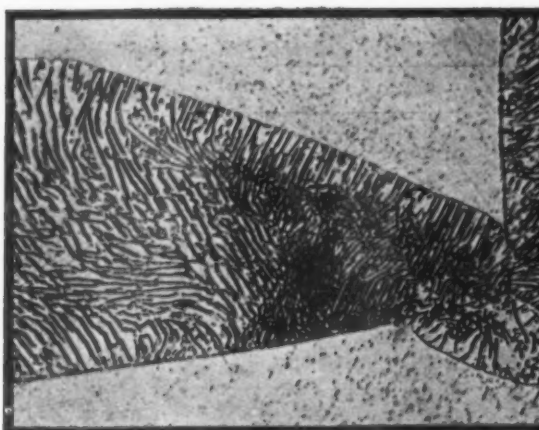


Fig. 1.—Precipitate growing from the grain boundaries. Magnesium + 8% aluminium. Solution treated and quenched. Precipitated 4 hours at 250° C. $\times 600$.

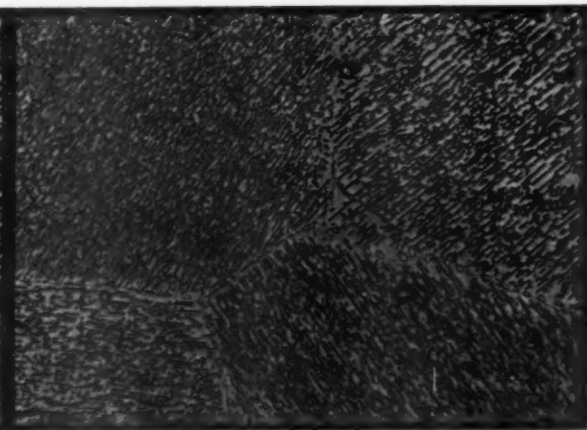


Fig. 2.—Precipitate within the grains. Magnesium + 8% aluminium. Solution treated and quenched. Precipitated 6 hours at 200° C. $\times 600$.

A study of the mechanical properties of a precipitation treated commercial alloy—Elektron AZ. 91 (containing about 10% aluminium, 0.4% zinc, 0.25% manganese)—showed that the best properties are associated with fine precipitate, although the actual form of the precipitate is not critical.

Plastic Deformation of Magnesium

While researches to expand the knowledge of orientation, slip and twinning in magnesium alloys, of particular importance in connection with wrought alloys, are known to be progressing, little information has been published.

TABLE II.—BRITISH AND AMERICAN SPECIFICATIONS FOR MAGNESIUM ALLOY SAND CASTINGS.

Alloy Designations.	Alloy Condition.	Source and Number.	Current Specification and Specification Requirements.											Minimum Tensile Property Requirements.		
			Chemical Analysis. Maximum or Range of Values of Elements Specified.											Proof Stress T.S.I.†	Ult. Stress T.S.I.	% Elong. on 2 in.
			Al.	Zn.	Mn.	Pb.	Cu.	Si.	Fe.	Ni.	T.I.* or T.O.I.	Mg.				
Elektron AM. 505 Downmetal M AM. 403	As cast	British D.T.D. 140A	0.2	0.2	2.5 max.	—	0.2	0.4	—	—	0.3	Rem.	—	6.0	3.0	
		Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy B.	—	—	1.20 min.	—	0.05	0.3	—	0.01	0.3	Rem.	—	5.3	3.0	
		A.S.T.M. B.80-41T, Alloy 11	—	—	1.20 min.	—	0.05	0.3	—	0.03	0.3	Rem.	—	5.3	3.0	
Elektron AZ91 Downmetal H AM. 265	As cast	British D.T.D. 59A	8.5 max.	3.5 max.	0.5 max.	0.4	0.4	0.4	0.1	Sn 0.4	—	Rem.	4.0	9.0	2.0	
		Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy A.	5.3-6.7	2.5-3.5	0.15 min.	—	0.05	0.3	—	0.01	0.3	Rem.	4.5	10.7	4.0	
		A.S.T.M. B.80-41T, Alloy 4	5.3-6.7	2.5-3.5	0.15 min.	—	0.05	0.3	—	0.03	0.3	Rem.	—	10.7	4.0	
	Solution treated	British D.T.D. 289	8.5 max.	3.5 max.	0.5 max.	—	—	—	—	1.0	0.3	Rem.	4.5	13.0	6.0	
		Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy B.	5.3-6.7	2.5-3.5	0.15 min.	—	0.05	0.3	—	0.01	0.3	Rem.	4.5	14.3	7.0	
Elektron A.8	Solution treated	A.S.T.M. B.80-41T, Alloy 4	5.3-6.7	2.5-3.5	0.15 min.	—	0.05	0.3	—	0.03	0.3	Rem.	—	14.3	7.0	
		British D.T.D. 289	8.5 max.	3.5 max.	0.5 max.	—	—	—	—	1.0	0.3	Rem.	4.5	13.0	6.0	
Elektron AZ. 91	As cast	British D.T.D. 136A	9.0-11.0	3.5 max.	0.5 max.	—	—	—	—	1.5	0.3	Rem.	4.5	8.0	—	
		A.S.T.M. B.93-41T, Alloy 2 (Ingot only; no tensile properties required).	9.4-10.6	—	0.15 min.	—	0.04	0.2	—	0.02	0.3	Rem.	—	—	—	
Downmetal C AM. 249	Solution treated	British D.T.D. 281	9.0-11.0	1.0 max.	0.5 max.	—	—	—	—	1.0	0.3	Rem.	5.0	13.0	4.0	
		British D.T.D. 285	9.0-11.0	1.0 max.	0.5 max.	—	—	—	—	1.0	0.3	Rem.	6.5	13.0	1.0	
AM. 269	As cast	Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy C.	8.3-9.7	1.7-2.3	0.1 min.	—	0.05	0.3	—	0.01	0.3	Rem.	4.5	8.9	—	
		A.S.T.M. B.80-41T, Alloy 17	8.3-9.5	1.7-2.3	0.13 min.	—	0.04	0.2	—	0.02	0.3	Rem.	—	8.9	—	
Downmetal C	Solution treated	(There is no equivalent British alloy)	—	—	—	—	—	—	—	—	—	—	—	—	—	
		Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy C.	8.3-9.7	1.7-2.3	0.1 min.	—	0.05	0.3	—	0.01	0.3	Rem.	4.5	14.3	6.0	
	Fully heat treated	A.S.T.M. B.80-41T, Alloy 17	8.3-9.5	1.7-2.3	0.13 min.	—	0.04	0.2	—	0.02	0.3	Rem.	—	14.3	6.0	
Joint U.S. Army, Navy, Aeronautical AN-QQ-M-56, Alloy C.		8.3-9.7	1.7-2.3	0.1 min.	—	0.05	0.3	—	0.01	0.3	Rem.	8.0	15.2	1.0		
		A.S.T.M. B.80-41T, Alloy 17	8.3-9.5	1.7-2.3	0.13 min.	—	0.04	0.2	—	0.02	0.3	Rem.	8.0	15.2	1.0	

* T.I. = Total Impurities British specifications. T.O.I. = Total other impurities U.S. specifications.
 † Proof stress at 0.1% permanent set British for British specifications and 0.2% for U.S. specifications.



Fig. 3.—Mosaic form of precipitate. Magnesium + 8% aluminium. Solution treated and quenched. Precipitated 6 hours at 150° C. $\times 600$.

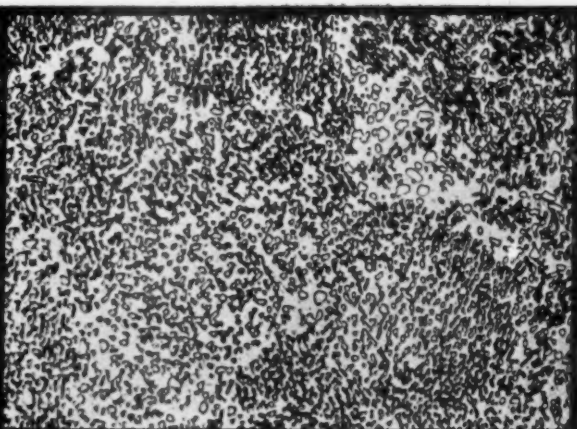


Fig. 4.—Spheroidised precipitate. Magnesium + 12% aluminium. Solution treated and quenched. Precipitated 72 hours at 250° C. $\times 600$.

The mechanism of plastic deformation in high purity magnesium at elevated temperatures (up to 300° C.) has been studied by Bakarian and Mathewson.¹² The results of tests on single crystals indicated that slip on the basal plane in the original material, twinning on the {102} plane, slip on the basal plane of the twinned regions, and fracture along the {101} plane are the only mechanisms operating during compression stressing, prior to the onset of general break-up. Tension tests proved that the first-order diagonal axis in the plane of slip is the slip direction, whether slip occurs on the basal plane (001) or the first-order pyramidal plane {101}. The authors present proof of single and double slip on the first-order pyramidal planes {101} and conclude that slip functions on one plane until the symmetry position is reached between equivalent slip directions, at which point double slip comes into play in a manner analogous to that found in face-centred cubic metals.

The practical aspect of plastic working of magnesium alloy sheet is the subject of an interesting American publication by Lehnhardt,¹³ the subject matter indicates that the Americans have been doing useful work in this direction in recent years. It is stated that the development of the deep-drawing process for magnesium alloys has facilitated the production of such aircraft parts as engine oil tanks, nose spinners, wheel dust covers, hub caps and many other similar parts.

Welding

The fabrication of magnesium alloy structures by autogenous welding which involves the use of a special flux possessing the properties of dissolving or destroying oxide skins and preventing contact between atmospheric oxygen and liquid alloy is widely used in the aircraft industry. An alloy containing 1.5% manganese (Elektron AM. 503) in the form of sheet is readily weldable and is being used in large quantities for the manufacture of sheet fairings, oil, fuel and other liquid tanks for aircraft. An alloy containing 6% aluminium, 1% zinc and 0.3% manganese (Elektron AZM) in the form of tube extrusions is used also for the fabrication by

welding of such parts as aircrew seats; magnesium alloys containing higher percentages of aluminium and zinc are not normally welded owing to the tendency for hot-short phases to separate from the liquid alloy during the welding process with consequent risk of crack formation.

Researches in this country have resulted in improvements in quality of the flux used, and in production, welds of the highest quality are readily obtainable.

In the U.S.A. efforts have been directed, by technicians of the Northrop Aircraft Inc., and the Dow Chemical Co., to the perfection of an arc-welding process and the development of the so-called "Heliarc" process has been reported. Hitherto electric arc welding has not been found suitable for magnesium alloy sheet or tube welding, although some success has been claimed in the welding of castings. Pavlecka¹⁴ claims that the "Heliarc" process opens a new world of design opportunities to aircraft engineers and envisages the all-welded magnesium alloy plane. In essence the process consists of shielding the electric arc with a blanket of inert helium gas which prevents oxidation of the molten weld metal and eliminates the necessity for the use of a flux. A sheath of pure helium gas is blown from orifices in a specially designed torch and which entirely surrounds a central pencil or electrode of tungsten, from which a direct current arc passes to the work to generate the required heat; the tungsten electrode is used with reversed polarity, the magnesium alloy being the anode; this prevents crater formation. Loose and Orban¹⁵ have considered the possibilities of the "Heliarc" process from a metallurgical aspect and have published some interesting data. It is claimed that the range of magnesium alloys that may be readily welded has been so greatly widened that all the commercial alloys may be welded. Correlations of tungsten rod size and range of allowable current have been established, and limiting figures of undesirable constituents in the helium—e.g., carbon dioxide, hydrogen, nitrogen, hydrocarbons and moisture have been ascertained; in this respect it is interesting to note that nitrogen, probably the most

¹² P. W. Bakarian and C. H. Mathewson. *Metal Technology*, April, 1943, 10 (3).

¹³ C. E. Lehnhardt. *Iron Age* March 18, 1943, CLE (11), 45-51.

¹⁴ H. V. Pavlecka. *Iron Age*, September 17, 1942, 150 (12), 74-76.

¹⁵ W. S. Loose and A. R. Orban. *The Welding Journal*, December, 1942, 21 (12), 5988-6078.



By Courtesy of Essex Aero, Ltd.

Fig. 5.—Fabrication of magnesium alloy aircraft petrol tank by autogenous welding.

insidious impurity, when present to the extent of 7%, though insufficient completely to impair weldability, is said to reduce the welding speed to one-third of that when using pure helium. The magnesium alloys which tend to be hot-short, due to the greater amount of lower melting-point compounds—i.e., those containing 6–10% aluminium and 1–3% zinc can be successfully welded when relatively high bead speeds are used. Thus, magnesium alloy castings containing defects can be repaired with the "Heliarc" process and welds of equal strength or stronger than the surrounding metal have been said to be obtained. Loose and Orban state also that the effect of zinc content on the tendency to hot-shortness is especially pronounced, and appears largely to govern the weldability of the alloy; this statement is in conformity with the findings of recent researches which have been made on the autogenous welding of magnesium alloys in the laboratories of Magnesium Elektron Ltd.

The advantages claimed for the "Heliarc" process of welding are interesting from a commercial point of view; however, the extent to which the "Heliarc" process has replaced the autogenous welding process in U.S. production lines is not known, nor is any other information available, substantiating the claims of the Northrop Aircraft Inc., and the Dow Chemical Co. The process, if adopted, is particularly applicable to the U.S. where supplies of helium are abundant and cheap. Argon, available in this country, is also suitable for the process, and investigational work is proceeding in various British centres.

Corrosion

Little information giving data concerning the effects of the constituents and impurities in magnesium alloys on their corrosion resistance has been published recently. A paper by McNulty and Hanawalt¹⁶ has reported an extension of the work described by Hanawalt, Nelson and

Peloubet.¹⁷ Using high-purity binary and ternary alloys of magnesium with aluminium and manganese, the tolerance limits for iron have been shown to be higher for magnesium than for magnesium-aluminium alloys. It is suggested that impurities such as iron are responsible for galvanic attack, and if present in sufficient quantity can cause rapid, unretarded corrosion, and that low concentrations of impurities may consist of such widely spaced inclusions that the corrosion process has not laid a second inclusion bare before the first inclusion is undermined and removed.

Much work is still being carried out on improvement of protective schemes for magnesium alloys and on the development of new protective treatments both of a chemical and electro-chemical nature; generally, however, the protective films formed have not been of sufficient value to replace the protective film formed in chromate baths—e.g., the acid-chromate bath or the R.A.E. baths.

One of the drawbacks associated with the acid-chromate bath—the small dimensional loss (about 0.0005 in.) of alloy surfaces during treatment—has been the subject of

work carried out in the laboratories of Magnesium Elektron Ltd.,¹⁸ and a modified acid-chromate bath* has been devised. This contains only 75 ccs. of nitric acid per litre of water (as compared with about 200 ccs. of nitric acid in the standard bath) together with 150 grms. potassium dichromate, and, in addition to reducing the metal dissolved during treatment, the films formed in the bath have a rather greater protective value (against the effects of immersion in 3% sodium chloride solution) than the standard film.

Parkinson and Cuthbertson¹⁹ have investigated the anodic oxidation of magnesium alloys by electrolytic treatment in a hot, dilute solution of chromic acid, and have shown that using either alternating-current or preferably alternating current and superimposed direct-current adjusted so that the mean value of the applied e.m.f. is zero, films possessing good corrosion-resisting properties (particularly under the salt-spray test) can be formed on Elektron AM. 503 (magnesium + 1.5% manganese), but not on the aluminium containing alloy Elektron A.8 (magnesium + 8% aluminium, 0.4% zinc, 0.3% manganese). The process has, however, no commercial possibilities, since the films are not materially different in quality from those resulting from the simpler and cheaper dip process.

The practical value of protective treatments for magnesium alloys has been discussed by Bushrod,²⁰ who states that in general the treatment used for magnesium alloys do not produce films of sufficient protective power to justify components so treated being put into service in which corrosive conditions may be met without further protection; it is becoming more and more evident that the films formed should be considered

17 J. D. Hanawalt, C. E. Nelson and J. A. Peloubet. *Metals Technology*, September, 1941, VIII (6).

18 C. J. Bushrod. *Magnesium Review and Abstracts*, April, 1943, III (3), 69–69.

19 N. Parkinson and J. W. Cuthbertson. *J. Inst. Metals*, March, 1943, 60 (3), 109–129.

20 C. J. Bushrod. *Magnesium Review and Abstracts*, October, 1943, III (5), 114–119.

* British Patent application 7233/42.

16 R. E. McNulty and J. D. Hanawalt. *J. Amer. Electrochem. Soc.*, 1942 81, 423.

War Emergency Copper-Tin Base Alloys and Other Low-Tin Alloys

By R. F. Hudson

(Phosphor Bronze Co., Ltd.).

Considerable changes have been made in the composition of many non-ferrous alloys in regular use, largely due to changes in availability of some metals. These changes have necessitated some differences in technique, and in this article the new specifications for gunmetal, phosphor bronze and brass are considered; some foundry aspects of alloys covered by several specifications are discussed in relation to both sand and chill castings.

Foundry and Metallurgical Aspects

SOON after the loss of Malaya it was decided in the national interest to conserve tin, and, where possible, copper, as both of these metals were in short supply, and it was therefore proposed by the British Standards Institution to introduce new war-time emergency specifications to this end. It was also agreed, in conjunction with Government Departments and the Institute of British Foundrymen's Non-Ferrous Technical Sub-Committee, to lower the standard of the specifications, as it was felt that many castings previously made in A.G.M. (BSS. 383) 2 B.8 (BSS. 1058) or the like, could be safely made in some lower-grade material without sacrificing its serviceability. Also by the use of these new specifications the use of scrap and secondary ingots could be greatly extended.

Virgin metal was to be used only for castings to withstand the highest stresses, and in these cases BSS. 1021/2 was to be used with an intermediate analysis of 88% copper, 8% tin, and 4% zinc, this alloy coming within the American Navy G. Specification 46 M.69.

The following article deals only with the new specification for gunmetal, phosphor bronze and brass. The War-time Emergency Specifications BSS. 1029/30 and BSS. 1031/2 for silicon bronze and aluminium bronze do not come within its scope. Some foundry aspects of the following will be dealt with in both sand and chill-cast state.

B.S.S. 1022	Gunmetal Castings.
B.S.S. 1024	Leaded Gunmetal Castings.
B.S.S. 898	85/5/5/5 Leaded Gunmetal.
B.S.S. 1059	2 B.8 Phosphor Bronze.
B.S.S. 1061	Leaded Phosphor Bronze.
B.S.S. 1026A	70-80% Copper-brass Castings.
B.S.S. 1028B	62-70% Copper-brass Castings.

It is felt that it is unnecessary to deal with the lead-free gunmetals and phosphor bronzes, as these alloys are primarily made from virgin metals, and, secondarily, they have many points in common with the leaded bronzes, such as melting, etc., which will be covered later.

Detrimental Impurities and Behaviour of Subsidiary Metals

Many elements and a wide range of the main constituents are allowed in the new alloys, which makes it possible to obtain a large range of physical properties, both bad and good, and so it is wise when ordering either ingots or scrap to order from a reputable supplier, and also to specify desired analysis and ingots of good mechanical condition.

Silicon and aluminium are the two most deleterious impurities. Silicon is not harmful in straight copper-tin alloys, but becomes extremely detrimental when lead is present, and the metal not thoroughly deoxidised, and so allowing a reaction between the silicon dioxide and lead oxide to form lead silicate, which often gives the casting a whitish appearance, and has serious results on the pressure tightness and physical properties of the alloy.

Aluminium is likewise dangerous; 0.01% is sufficient to cause gross leakage and dirty machined surfaces through the formation of aluminium oxide. Aluminium can, however, be easily observed in the molten metal through the formation of a film which, on breaking, reforms immediately and in unmachined castings is shown on the extremities through the appearance of a whitish glossy sheen. In brass, aluminium is just as obnoxious as in bronze in promoting defective castings, although it is sometimes added to reduce zinc fumes, therefore, for consistent results the aluminium content must be nil.

Antimony up to 0.3% is not known to be harmful, but has a slight hardening effect.

Phosphorus, when only existing in the region of 0.05% in gunmetal and bronzes is beneficial, having a deoxidising action on the metal. Above this amount it hardens the alloy and causes rougher castings through metal penetration. Phosphorus in phosphorus bronzes is of course one of the main elements, forming with the copper a second bearing constituent, copper phosphide (Cu_3P) with a Brinell hardness of about 130, while the delta phase (copper-tin) is about 220. Phosphorus in sand-cast material increases the hardness at the expense of ductility. The same is also true with chill-cast phosphor bronze, but at the same time the strength is increased.

Nickel in brass and bronze is beneficial. It disperses the lead into small particles and toughens the material. There is, however, a tendency for an increased gas absorption if the metal is being melted under improper melting conditions.

Iron and tin are found in most bronzes. The tin increases the strength and up to 1% is advantageous. Above this, however, there is a tendency towards brittleness through the formation of delta. This is especially marked when in combination with a high zinc content. Tin also improves the corrosion resistance of brass. Iron is beneficial as a grain refiner. It is noted that bronzes required for pressure castings should have

the copper content on the high side of the specification, and BSS. 1025/6 is generally considered most satisfactory for pressure work.

General Conclusions and Recommendations

Bronze.—Arrange the principal elements so as to obtain the desired properties, remembering that an increase of zinc in gunmetal hardens the alloy and decreases its ductility, and so may replace tin to some extent, except for bearing purposes. No aluminium or silicon is permissible. Nickel increases pressure tightness.

Brasses.—For pressure castings work on high side of copper content, high iron and medium tin (1% maximum), aluminium and silicon nil. It is understood that these additions of extra metals are found in scrap or secondary ingots, and it is not intended that they should be added as new metals.

Melting Procedure

The melting of these alloys does not differ from that of the pre-war standard brass and bronzes, but a short note on melting practice might not be out of place here.

The conditions for good melting do not differ much between zinc-free alloys and those that contain zinc. It is true, however, that zinc-free bronzes are much more susceptible to melting defects than gunmetals and brasses. Where zinc is present the high vapour pressure protects the metal from the absorption of obnoxious gases, of which hydrogen is the most detrimental. Hence it is advisable to maintain a slightly oxidising atmosphere in the furnace and avoid all materials which might evolve reducing gases. A slightly higher melting loss might be noticed, but this is well worth while when considered against the high percentage of defective material from a furnace running under reducing conditions. A definite oxidising atmosphere should therefore be present in the furnace. This is readily obtained in forced draught furnaces, and indicated by the green tip to the flame at the flame outlet. However, in natural draught furnaces, a constant furnace atmosphere is not always prevalent, and if a neutral or slightly reducing one is usual an oxidising slag containing such material

as manganese ore, manganese dioxide, etc., should be used. In both cases fast melting is desirable, followed by a deoxidisation treatment with phosphorus, using about 0.5% of 10% phosphor copper, thereby adding 0.05% phosphorus to the melt. This converts certain of the oxides which rise to the surface of the melt and may be skimmed off. Stannous oxide is not so easily removed, and unless mechanically prevented from entering the mould by choke gates, etc., it will be found entrapped in the solidified metal.

More defective material is made through the absorption of reducing gases than through any other metal defect. This is especially the case with sand-cast phosphor bronzes, these alloys being most susceptible to this type of defect. Centrifugal or chill castings are not so liable to this defect as the amount of gas evolved on cooling is in relation to the rate of solidification.

Defects due to gas absorption are often misinterpreted and classed as oxidised metal. Red and discoloured fractures are often shrinkage cavities due to the absorption of gases during melting and subsequent evolution on cooling, and thus the gas pressure caused prevents adequate feeding of the casting.

This has been proved many times in the foundry, in slight cases red fractures are found with quite a thick skin of sound metal around the edges with a very slight depression in the runners. In extreme cases a dark-brown or even black-mottled fracture is observed with a thin skin of sound metal and no depression, or possibly even the risers are "spewed." In the high phosphor bronzes this porosity tends to increase through the prolonged freezing range, accompanied perhaps by improper pouring temperature and heavy metal section.

To illustrate the effect of furnace atmosphere on the properties of leaded gunmetal, Table I shows how an alloy of the same composition, and with exactly the same treatment during melting, reacts to various furnace atmospheres and flux additions. Virgin metal was used, the copper being melted first with or without a flux (1½% manganese ore). When liquid and approximately 40° C. above the pouring temperature, the melt was deoxidised with 0.05% P. and zinc, lead and tin well stirred in. Melts of phosphor bronze have been tested in the same manner—i.e., furnace atmosphere versus mechanical properties in both secondary ingots and virgin metal. Secondary ingots or scrap is, of course, the usual practice in order to conserve virgin metal. If virgin metals are permitted, the castings should be made from the first melt, and the metals not ingotted so as to reduce fuel consumption and melting loss.

Foundry Practice

No trouble should be experienced in the foundry when handling these war-time alloys, in fact in some respects they are more trouble-free than the old specifications. Contraction allowances are similar to those already in existence for A.G.M.—P.B. and naval brass. Only with BSS. 1027/8 need extra precautions be taken, as this alloy, especially when containing aluminium, has characteristics very similar to manganese bronze, and

TABLE I.—SHOWING GAS ANALYSIS AND PHYSICAL CHARACTERISTICS OF LEADED GUNMETAL.

Heat No.	Alloy.	Pouring Temperature, °C.	Flux.	Gas Analysis.				Physical Properties.			
				CO ₂ .	O ₂ .	CO.	H ₂ .	Water Vapour.	V.P., Tons/sq. in.	T.S., Tons/sq. in.	Elongation % on 2 in.
F.1	Virgin Metal— 86% copper 7% tin 5% zinc 2% lead	1,160	Nil	11.0	0.7	9.4	Nil	0.0014	9.0	14.3	16
F.7	Do.	1,160	Nil	11.0	2.4	2.2	Nil	0.0014	9.2	15.25	22.5
F.8	Do.	1,160	1½% Manganese ore	11.3	2.7	1.5	Nil	0.0014	9.8	18.8	39.5

the contraction allowance is midway between that of gunmetal and manganese bronze.

With reference to leaded gunmetal, these are readily cast and are usually gas-free, and make good pressure and corrosion resisting alloys. Top pouring through pencil or small gates from a single pouring basin into blind risers makes a very effective running method for large castings, such as bushes, cylinders and rams, the standard practice of choke gates, strainer cores, etc., being usually suitable for small work.

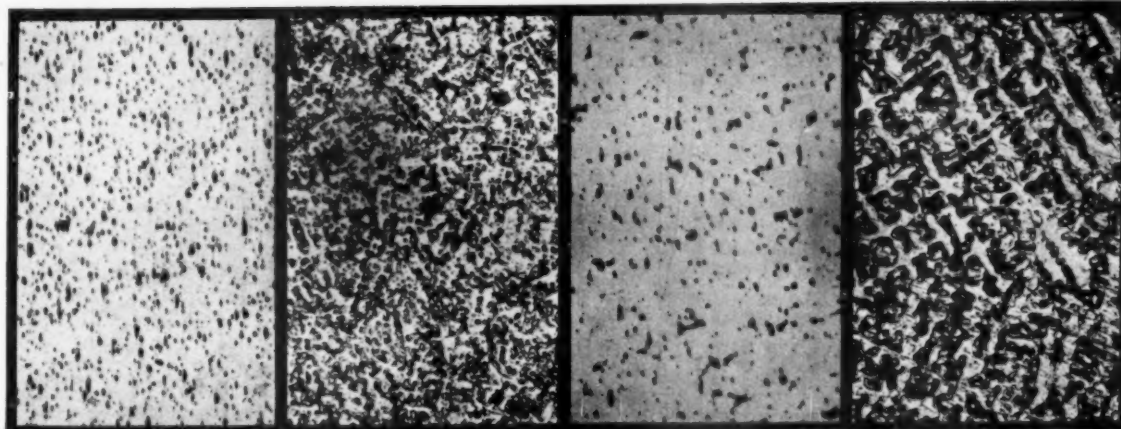


Fig. 1.—Centrifugally cast leaded gunmetal. Unetched. $\times 50$.

Fig. 2.—Centrifugally cast leaded gunmetal. Etched. $\times 50$.

Fig. 3.—Sand-cast leaded gunmetal. Unetched. $\times 50$.

Fig. 4.—Sand-cast leaded gunmetal. Etched. $\times 50$.

Mechanical Properties

The mechanical characteristics of various gunmetals to certain analyses are given in Table II. The comparison can be seen between the lead-free and the leaded gunmetal in both the sand and chill-cast condition. The pouring temperature may be taken as the one most suitable for test-bars to the analysis in question. This approximates to general work of medium section, light work being cast a little hotter and heavy non-pressure work colder. The modified I.B.F. design of test-bar being used.

These alloys may also be centrifugally cast very successfully, and many thousands of castings are being

TABLE III.—SHOWING PHYSICAL PROPERTIES OF CENTRIFUGALLY CAST LEADED GUNMETAL

Alloy.	Y.P. Tons/sq. in.	Tensile Tons/sq. in.	Elongation % on 2 in.
88-54% copper	10.1	19.7	90
5.11% tin			
2.60% zinc			
3.40% lead			
0.15% P			
0.05% Fe			
0.15% Ni			

Figs. 1-4 show the superior structure of centrifugally cast gunmetal in the unetched and etched condition against sand-cast material to the same analysis. The

analysis is shown in Table III. The castings in question being slip rings, the much finer lead distribution and smaller cored structure being clearly visible. Incidentally the specific gravity of centrifugally cast material is higher.

Leaded Phosphor Bronze or BSS. 1060/1 is an alloy that is in everyday use, perhaps sometimes in a modified form for bearings and bushes to resist wear in many different designs. A high lead content being used when lubrication is doubtful, and in conjunction with heavy pressure and slow-running

TABLE II.—SHOWING MECHANICAL PROPERTIES OF GUNMETAL

Alloy, Cu, Sn, Zn, Pb	Method of Casting	Pouring Tempera- ture, °C.	Compression Tests, Tons/sq. in.		Physical Properties		Elongation % on 2 in	Izod Value, ft. lb.	Brinell Hardness No.
			0-1% P.S.	Break.	Y.P.	T.S.			
Admiralty gunmetal— 88/10/2	Sand	1,160	7.5	70	9.2	18.4	24	9	88
Leaded gunmetal 86/10/5/5	Sand	1,160	9.92	61.3	8.8	14.2	11	6	69
87.5/9.5/2/1	Sand	1,150	7.38	69.1	9.6	19.0	30	7	77
88/8/4	Sand	1,170	7.0	*	9.4	19.6	37	9	78
88/8/4	Chill	1,200	7.5	*	10.1	14.6	7	—	96
86/7.5/2	Sand	1,160	5.2	52	9.1	17.4	39	7	67
86/7.5/2	Chill	1,190	—	—	9.3	14.9	10.5	—	85
85/5/5/5	Sand	1,160	4.5	46.5	9.0	15.2	29	6	61
85/5/5/5	Chill	1,170	—	—	8.4	12.9	11	—	73

* 50% reduction in height at 100 tons. Test-pieces 1.50 in. long \times 1.00 in. diameter.

horizontally spun in the foundry to which the author is connected. Table III shows the very high test figures obtainable by this method. These bars are cut from the actual castings, while in most cases the test-bars representing a sand-casting give higher tensile results than from a bar cut from a casting. Thus the actual difference between the physical properties of centrifugal and sand castings are more than ever in the favour of spun castings.

speed, for example, bearings for rolling mills.

Given good melting, the other two main difficulties lie in sub-surface porosity and metal penetration of the sand.

The pouring temperature is very important, as quick solidification of the metal, especially in heavy sections, is extremely advantageous, resulting in sound castings with good bearing characteristics. Phosphor bronze is much more prone to porosity than many other alloys—

this is caused by the long freezing range. The first phase to solidify (alpha) at 890° C. and the last phase phosphide eutectic at 640° C., giving a range of 250° C. during which time the metal in the mould is in a semi-plastic condition, and as such is liable to certain deleterious results. This range varies with composition. To obtain gas-free metal, therefore, it is good practice to pour at a low temperature, and to use chills in the mould, using either metalchills or carborundum sand of high conductivity. Top pouring to ensure progressive solidification, by which lower casting temperatures may be used, is also advisable.

The phosphorus and lead contents are the two elements which cause rough castings and metal penetration into cores, etc. The higher these are, the more attention must be paid to sands and to mould and core dressings. A uniform fine-grained sand is required, but with sufficient permeability to allow all gases to escape. A sand with an A.F.A. permeability No. 30-60 is normally quite satisfactory.

Dry sand gives the best results, and for the mould dressing a good flaked graphite and clay wash applied by brush is satisfactory. There is a possibility that H₂ may be absorbed from the mould material, and when this occurs, accompanied by a residual gas content absorbed during melting, there is a definite danger of porous castings. This is another reason for quick solidification of the metal through the intermediate pasty period. For very heavy phosphor bronze castings loam or clay-bonded cores are advised, because oil-sand, unless very carefully supervised and coated with an impervious wash, is not so resistant to metal penetration.

It should always be remembered that quick cooling and chilling increases the Brinell hardness and promotes superior bearing characteristics. Zinc is allowed in BSS. 1060/1, but it is best kept to a minimum, as it tends to produce dirty castings.

The mechanical properties of leaded bronze both in the sand- and chill-cast condition at varying casting temperatures are shown in Table IV. It will be noted how the tensile and Brinell hardness increases as the pouring temperature decreases, but below a certain datum line the tensile decreases although the Brinell hardness is unaffected and still increases.

Leaded Brass

These alloys, while not difficult, may cause the greatest amount of inconvenience of all the new specifications under review; BSS. 1025/6 should give little trouble, but BSS. 1027/8 approaches manganese bronze practice, and extra contraction must be allowed for, also increased heads to counteract the extra shrinkage. Bottom pouring is sometimes essential to ensure clean castings.

The contraction allowance is approximately $\frac{3}{16}$ in. per foot for BSS. 1025/6 (Type A), and $\frac{1}{2}$ in. per foot for BSS. 1027/8 (Type B). The low zinc (Type A) is most satisfactory for pressure castings. Low-pressure castings and previously cast in gunmetal may be made in this brass, the best results are obtained by keeping the copper content high. For pressure castings of thin section high casting temperatures are advised in the region of 1,100°-1,200° C.



Fig. 5B.—U.S. Navy bar.

Fig. 5A.—Modified I.B.F. test-bar design.

Type B brass is more prone to cracking. It was noticed while casting wheels in this alloy, weighing 4 cwt., that when aluminium was present, even in minute quantities, cracking occurred, while with the same moulding technique and no aluminium good castings resulted. Tin up to 1% promotes easier running, and the lead contents easy machining.

The mechanical properties and pouring temperatures of Type A and B brasses are given in Table V. The test-bars used for the brasses were of the ordinary "keel" shape as used for manganese bronze. It will be

TABLE IV.—CHILL AND SAND-CAST LEADED-PHOSPHOR BRONZE: MECHANICAL PROPERTIES.

Mixture.	Analysis.						Yield Point, Tons sq. in.	Maximum Stress, Tons sq. in.	Elongation % on 2 in.	B.H. No.		Cast'g Temperature °C.	Compression Tons/s q.in.	
	Sn.	Cu.	Zn.	Pb.	Fe.	P.				Skin.	After 3/16 Mac'g.		0.1% P.S.	Break.
Secondary ingots	7.5	86.59	1.25	4.0	0.01	0.65	8.2	11.6	7	80	78.5	1,080	7.0	46.5
Sand-cast							9.2	13.2	9	94	81	1,040	—	—
Secondary ingots	7.5	86.59	1.25	4.0	0.01	0.65	12.0	20.0	11	115	96	1,200	9.75	53.0
Chill-cast							11.2	18.4	10	120	100	1,160	—	—

noted that the tensile strength increased as the temperature was lowered.

Type B brass is also being centrifugally cast every day, resulting in a big saving in phosphor bronze and gunmetals for such applications as roller bearings, cages, etc. Peculiarly, aluminium does not seem to affect spun castings, and the following results show the great superiority of this type of casting. The analysis is similar to that in Table V, excepting the addition of 0.1-0.2% aluminium to increase the fluidity when casting:—

0.1% proof stress	8.9 tons per sq. in.
Maximum stress	24.9 tons per sq. in.
Elongation	17% on 2 in.
B.H. No. 116	5 mm./750 kgs.
Isod value	12.5 ft./lb.

Test-bar Designs

All the test results quoted in the tables, with the exception of the brasses, have been obtained using test-bars to the I.B.F. design shown in Fig. 5, marked B.

This bar has always been found to give consistent and good results, especially with the gunmetal specifications. With phosphor bronze this bar also gives

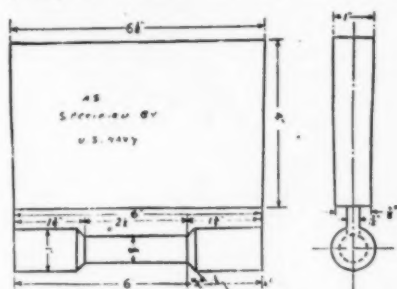
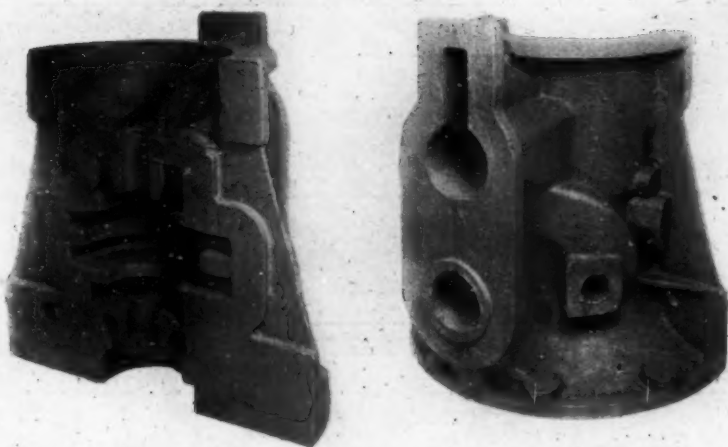


Fig. 6.—Dimensions of U.S. Navy bar.

excellent results, excepting that it is not quite so consistent as the U.S. Navy bar shown in Fig. 5, marked A. This bar is exceedingly satisfactory for all phosphor bronze alloys. In the case of Fig. 5, we have slightly increased the width of the head. Fig. 6 gives the dimensions of this bar as used in America.

The shaped bar under the block riser is formed by two split oil-sand cores, the upper half having two rectangular holes located at either end of the bar to joint the bar with the riser. Oil-sand is preferred for this core for the reasons already mentioned—i.e., quick cooling and minimum water vapour evolution. The mould portion is made in dry sand, but may on occasion be used green for gunmetal.



Courtesy of Messrs. Drysdale and Co., Ltd.

Fig. 7.—Rotary pump body in 86-7-5-2. Approximate weight 4.5 cwt.

These defects only refer to melting defects in test-bars, but may also be taken to denote the relative failure in castings, as test-bars are cast from the same melt and, further, are cast to a standard design to promote adequate feeding, etc., while castings are made to many designs and are often very inadequately fed, which would make many defects more pronounced. This is further proof as to the importance of eliminating hydrogen or any other H_2 evolving material from contact with molten bronze, especially phosphor bronze.

TABLE V.—PHYSICAL PROPERTIES AT VARIOUS TEMPERATURES OF TYPE A AND B BRASS.

Mixture.	Analysis							Yield Point, Tons/sq. in.	Maximum Stress, Tons/sq. in.	Elongation % on 2 in.	Brinell Hardness No.	Cast'g Temperature, °C.	Compression, Tons/q. in.	
	Sn.	Cu.	Zn.	Pb.	Fe.	Al.	Ni.						0.1% P.S.	Break.
Virgin Ingots, Type A	0.40	72.15	21.85	4.71	0.42	Nil	0.47	5.6	12.6	27	65.5	1,040	—	—
								5.2	11.75	23	62.4	1,000	—	—
								6.8	15.0	23	65.8	980	—	—
Secondary Ingots, Type A	0.33	70.25	26.60	2.45	0.36	Nil	0.11	4.0	10.5	34	48.8	1,040	—	—
								4.0	11.8	40	52.0	1,000	—	—
								4.8	13.2	42	68.5	960	—	—
Secondary Ingots, Type B	0.27	63.64	32.97	2.80	0.19	0.03	0.10	6.0	9.2	24	64.9	1,040	—	—
								4.8	14.6	38	59.5	1,000	4.65	74
								5.4	16.3	39	63.0	960	—	—
Secondary Ingots, Type B	1.22	63.80	31.56	2.93	0.35	Nil	0.14	6.8	8.1	6	57.9	1,040	—	—
								7.6	14.8	18	56.3	1,000	—	—
								6.4	15.5	17	57.2	960	—	—

Many bar designs giving indifferent results have been used in the past, and it would seem desirable that the British Standard Institute recommend certain designs for use with different specifications, and so give the founder the benefit of established experience and practice.

W. B. George¹ gives his findings after checking results on test-bars that have failed, that losses may be classified approximately as follows, according to the defect that caused the failure:—

Defect.	%.
Water vapour	75
Gassed metal	10
Hot pouring	5
Cold pouring	3
Oxidised films within the metal	2
Other causes	5

¹ "Some Causes of Porosity in Bronzes." Non-Ferrous Division A.F.A. Convention, 1942.

brasses are eminently suitable. The substitution of these have not shown any increase in scrap either in the foundry or in service, and in many cases a reduction has occurred. F. Hudson² states that the leaded bronzes are comparable with the lead-free high tin alloys for corrosion resistance to fresh and sea-water, and also at elevated temperatures. Bronze valves and fittings may be employed up to 260° C. when cast in 86/7/5/2, and 204° C. when cast in 85/5/5/5. He also states that cast brass (Type A) is more suitable than gunmetal for use with fuel oil, petrol, etc. A comparison of alloys used previously with those used now is given in Table VI; it will be noted that equal or better results are now obtained.

² *Prod. of I.B.F.*, 1941-2. Vol. 35, Part II.

Practical Uses and Applications of these Low-Tin-Copper Base Alloys

Very many tons of castings have been made and are being made every week in these alloys in the foundries with which the author is associated, and very appreciable saving is made in copper and tin when replacing A.G.M.—Admiralty P.B.—and 2B.8, etc. It has been recognised that lead-free bronzes have been used in the past for many purposes for which the leaded bronzes and

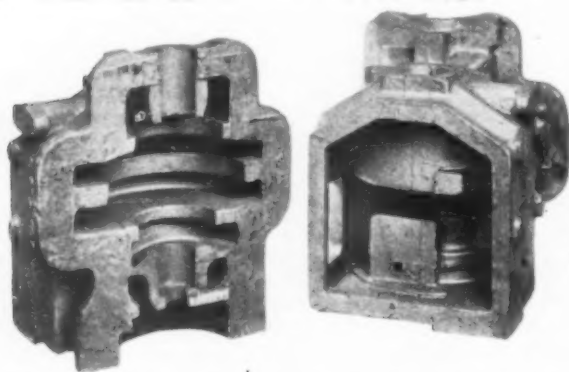
TABLE VI.—SOME APPLICATIONS OF LOW-TIN BRONZES.

Alloy previously Used.	Alloy now Used.	Application.
Gunmetal— 88/10/2	86/7/5/2	Valve bodies, 100-1,500 lb./sq. in. hydraulic pressure. Pumps, cylinders, bushes, glands, 100-1,000 lb./sq. in. hydraulic pressure. Steering caps and bearings. Gear cases and covers, and certain structural work. Wagon brasses unlined, rolling mill bearings, etc. White-metalled bearings. Bushings for graphited bushes at elevated temperatures, with or without adequate lubrication.
Gunmetal— 88/10/2 88/10/2 87/9/3/1	85/5/5/5	Valve bodies, 100-300 lb./sq. in. pressure. Pumps, bushes. Gear cases, water heaters, 100-300 lb./sq. in. Supported white-metalled bearings. Fire-hose connections, cocks, taps, tubes and bends for use with hot oil. Many other miscellaneous purposes. Slip rings (centrifugally cast).
Phosphor bronze— Admiralty P.B. 2 B.8 B.S.S. 421	B.S.S. 1061.	Rolling mill bearings, slow speed—inadequate lubrication Bushes and bearings, high lead—inadequate lubrication Bushes and bearings, low lead, high speeds—good lubrication Gear wheels, lower loads, slow and medium speeds
85/5/5/5	Brass, Type A	Pressure castings, taps, cocks, fittings, etc., 100 lb. hydraulic pressure. Castings in contact with oil and petrol. Fire-hose fittings.
88/10/2 88/7/5/2 85/5/5/5	Brass, Type B	Roll-bearing cages (centrifugally cast), previously A.G.M. Non-pressure castings, deck fittings, hand-wheels. White-metalled bearing backings. Earth shields. Non-magnetic bogey-wheels, etc.

Some castings made in the foundries of the Phosphor Bronze Co. in the low tin content gunmetals are illustrated in Figs. 7-11. Most of these were originally cast in 88/10/2. Many illustrations showing substitution of B.S.S. 1061 for 2 B.8 and B.S.S. 421, etc., could be shown if space permitted, and leaded brass for gunmetal.

Chill Castings

These specifications also allow for chill castings of solid bars and bushes. The previous Tables II and IV



Courtesy of Messrs. Dugdale and Co., Ltd.

Fig. 8.—Small rotary pump bodies in 86-7-5-2.

give the mechanical properties of certain chill-cast alloys. It should, however, be pointed out that the phosphor bronze alloys, when chill cast, will produce much better castings with a very much lower percentage of scrap than the gunmetals, which, through their shorter freezing range and in conjunction with the quick chilling action of the metal mould, tend to solidify instantaneously, and hence, on machining, blow-holes from entrapped gases appear.

For the same reason centre porosity often occurs, due to lack of feeding. Bad cases are visible to the eye, but

in all gunmetals some centre porosity may be seen under the microscope, and this results in low tensile strengths. However, through the formation of extra delta when

Fig. 9.—Valve bodies in 86-7-5-2.

Courtesy of White's Marine Eng. Co., Ltd.

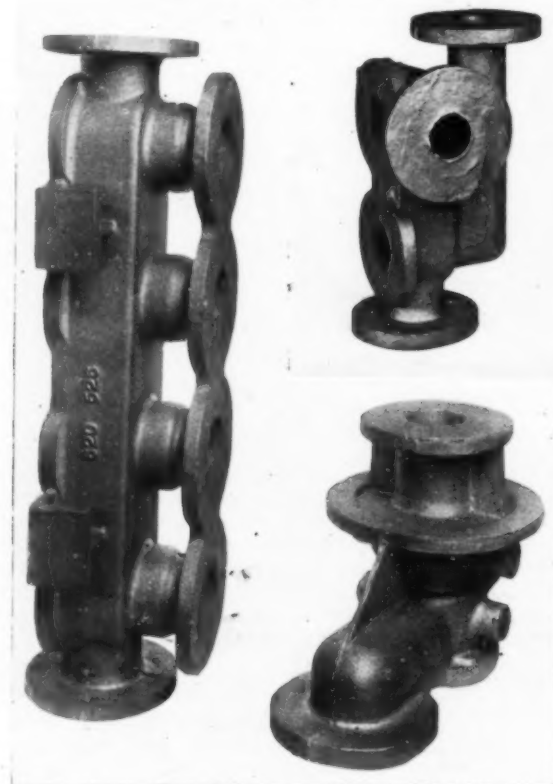


Fig. 10.—Some small castings in 85-5-5-5.



chill cast these are lower in strength in comparison with sand castings, the extra delta promotes superior bearing properties than is obtained in sand-cast gunmetals.

With P.B. Specifications BSS. 1058/1061, very fine distribution of the delta and phosphide constituent guarantees very excellent bearing characteristics, but, unlike gunmetals, the strength rises as the phosphorus content increases—25 tons per sq. in. is common with a P content of 1.5%. On heat-treatment, this may be still slightly increased in company with the Izod value, but with a deterioration in its bearing properties.

With all chill castings high-pouring temperatures are essential to prolong the freezing range. Chill-cast sticks and tubes are normally cast in 2 ft. lengths, but shorter

lengths show a lower percentage of defects. The main features which must be correct to ensure good results are as follows:—

1. Clean cast-iron moulds.
2. Correct mould temperature.
3. Correct mould dressing, not excessive, usually rape oil and plumbago.
4. Correct pouring temperature. Usually higher than for sand castings of similar design.
5. Correct pouring speed.

Again, it must be emphasised that it is very necessary to use secondary ingots of approved analysis, and free from oxides, absorbed gas, etc., or unreliable results will occur.

Cast Iron and the Foundry Industry

By J. E. Hurst, D.Met.

The record of the iron-founding industry in the present emergency is of an outstanding character, and, while a complete review of the progress achieved would not be expedient at this time, some aspects of achievements with cast iron are reviewed, attention being directed more particularly to metallurgy, melting and moulding.

THE foundry industry is one of the industries concerned with the conversion of metals and alloys into useful shapes and articles, and utilises the method of casting the metals and alloys into moulds previously formed to the shapes desired. It thus embraces the preparation of suitable metals and alloys, the conversion of these to the molten state, and the production of moulds which, on filling with molten metal, are translated into the desired castings, and a review of the foundry industry, with particular reference to cast iron, can be dealt with very well in this manner under the more restricted headings of its metallurgy—melting and moulding.

Metallurgy

In any casting the primary requirement is soundness and freedom from internal defects, and this is a consideration which stands in front of all other qualities. One of the most significant elements in cast iron from the point of view of its influence on soundness is phosphorus, and with the object of conserving low-phosphorus materials, such as hæmatite, steel scrap and refined iron, foundrymen are expected to use as much of the native high-phosphorus irons as possible. Up to the present there is little evidence that castings have suffered from the curtailment of supplies, and, as a whole, foundries have adjusted themselves very satisfactorily to the altered condition.

The Cast-Iron Sub-Committee of the Institute of British Foundrymen, in their report on meeting the raw materials supply position in grey-iron foundries,¹ collected the experiences of various foundries in dealing with problems arising from the changed raw materials supply position. They were able to give a number of

examples from actual practice, and to make suggestions for meeting conditions of further stringency in supplies. The restrictions in low-phosphorus materials have largely been met by:—

(a) Substitution of hæmatite by low-phosphorus blast-furnace pig iron with phosphorus about 0.4%, resulting in a general increase in phosphorus. If the proportion of hæmatite in the charge did not exceed 30%, the resulting increase in phosphorus was only about 0.1%, and this rarely caused any difficulty.

(b) Replacement of hæmatite by refined pig iron. Low-phosphorus pig iron is obtainable at a premium, and it has been possible to maintain castings at the same phosphorus level as before, while at the same time dispensing with the use of a certain amount of steel scrap. The use of very low-phosphorus refined pig iron is discouraged, and a slight increase in phosphorus, as indicated in (a) above, can be tolerated.

(c) Very careful control over the metal mixture, and especially over carbon and silicon contents, whereby the deleterious effects of phosphorus on mechanical properties may be eliminated or counter-balanced. The use of late silicon additions is strongly recommended.

(d) By giving careful attention to improved methods of running and rising—e.g., by the increased use of feeding heads, by the adoption of new running methods incorporating "atmospheric feeding," and special types of feeder gates.

(e) By adopting centrifugal casting methods wherever practicable.

(f) By careful attention to pouring temperature.

(g) By the correct use of denseners.

¹ Report by the Cast-Iron Sub-Committee of the I.B.F. on Meeting the Raw Materials Supply Position in Grey-Iron Foundries, *Foundry Trade Journal*, August 12, et seq, 1943.

Ladle Metallurgy

The strong recommendation in the above report given to the practice of late silicon additions serves to draw attention to this important development in iron-founding practice. The terms "ladle additions," or "late additions," used in reference to adjustments in the composition of cast iron in a sense are alternative and in a narrow sense, and including the term "inoculated" they refer to the treatment of molten cast iron in the ladle by the addition of elements which bring about graphitisation. The general phrase, inoculated cast iron, is now widely used and understood, and in the broadest sense refers to those cast irons in which the desired properties have been obtained either wholly or in part by the addition of some element or alloy to the molten metal in the ladle.

The justification for the use of a special term for cast irons so treated rests on the discovery that the action of graphitising elements such as silicon is different when added to the already molten metal in a crushed form than when included with the pig iron and scrap, and melted down in the cupola charge. The effect produced by late additions of silicon in a suitable form to a molten white iron is so pronounced, having regard to the quantity added, as to fully justify the special use of the term "inoculation" to identify this procedure, for as a procedure it yields the highest strengths available yet from grey irons tested in the "as-cast" state.

It is of some importance to stress the fact that the production of such irons involves a process or a procedure, and in its application to the production of high-duty cast irons it is necessary that this should be carefully planned and precisely carried out.^{2,3}

The Cast-Iron Sub-Committee of the Institute of British Foundrymen in drawing attention to the value and importance of this technique in its general application point out that the final silicon content of cast-iron casting must be controlled to give suitable relationship between carbon and silicon contents, and the rate of cooling which is determined by the sectional thickness of the castings. Late silicon additions made to the metal at the furnace spout must also conform to the above general principle, but the final silicon content can usually be somewhat higher than normal, other things being equal, with beneficial results.

Summarising what has already been published, the Sub-Committee recommended that between 0.5% and 1.0% silicon should form the late addition, irrespective of the amount of silicon in the metal as charged to the furnace. While early practice favoured the introduction of ferro-silicon in powder form, granular form of pea size, or even larger, is now preferred. This preference, however, may depend to a certain extent on the silicon content of the ferro-silicon readily available. It is usually considered that the powder form is quite effective when high-silicon ferro-silicon is being used, as the bulk to be added is not very great. With ferro-

silicons of lower silicon content, however, it is better to use pea-size material.

Inoculation should take place as late as possible, since its beneficial effect disappears after an interval of 15 to 20 mins. Where fairly large quantities of metal are being treated, silicon treatments should be so arranged that the late addition is made near the end of the last tap, so that not more than, say, 10 mins. time elapses between the completion of the silicon treatment and the pouring of the last mould from that particular batch of metal.

High Duty Inoculated Cast Irons

The outstanding examples of inoculated cast irons for high duty requirements to meet the higher ranges of B.S.I. Specification 786 are now well known as the grade of mearhanite cast iron produced by the addition of calcium silicide to molten cast iron of predetermined initial composition, Ni-Tensyl, and some of the acicular irons. These latter are perhaps the most recent additions to the range of high-duty cast-irons prepared in this manner. The Ni-Tensyl process was described in detail by F. B. Coyle some years ago, and depends upon the effect of adding proportions of nickel and silicon to a molten low-carbon, low-silicon base iron. Such irons are melted in cupolas, air furnaces or electric furnaces, and the low-carbon, low-silicon requirements are secured by the use of steel scrap or low-carbon-refined white irons. Structurally such inoculated irons are fully pearlitic with relatively fine flake graphite, and when cast under ideal conditions are very uniform in properties in varying sections. Such irons are used for many types of engineering castings where high stresses have to be met, or where reduced sections are desired. In some cases where the ductility of cast steel is not essential inoculated irons are acting as substitutes.

A very interesting series of experiments in the study of inoculating effects were undertaken by myself some years ago.⁴ The experiments were undertaken to study various methods of adding to the higher melting point metals—molybdenum, tungsten and titanium—to cast iron, and the results described referred to a method of making the additions by the use of the oxide of the alloying element in conjunction with a reducing agent. The reducing agent chosen was calcium silicide and intimate mixtures of powdered calcium silicide and molybdic oxide, tungstic oxide and titanium oxide were added to molten white iron melted in a crucible.

A few of the results are collected together in Table I. These results show the effect of inoculation, using

3 Braidwood, J.I.E.F., 1941 42.
4 Hurst, J. E. F.T.J., October 19, 1939.

TABLE I.—EXPERIMENTS ON THE ADDITION OF CALCIUM SILICIDE AND OXIDES OF MOLYBDENUM TUNGSTEN AND TITANIUM TO MOLTEN WHITE IRON.

Late Addition.	Chemical Composition.										Transverse Strength.	Tensile.	Brinell.	
	T.C.	GR.	CC.	SI.	S.	P.	Mn.	Mo.	W.	TI.	Mod. of Rupture.	Def. in.	Tons sq. in.	Edge. Centre.
NiI	3.11	—	—	0.75	0.037	0.048	0.48	—	—	—	—	—	—	—
Calcium silicide ..	2.92	2.03	0.89	1.54	0.024	0.055	0.46	—	—	—	43.75	0.42	25.92	217 217
CaSi + MoO ₃ ..	3.00	1.87	1.13	1.62	0.011	0.054	0.44	0.315	—	—	47.2	0.43	24.74	235 228
CaSi + MoO ₃ ..	2.89	1.97	0.92	1.76	0.007	0.051	0.45	1.12	—	—	56.6	0.42	31.62	269 269
CaSi + WO ₃ ..	3.08	1.96	1.12	1.08	0.02	0.057	0.44	—	0.31	—	36.9	0.31	19.6	207 217
CaSi + WO ₃ ..	2.91	2.02	0.89	1.50	0.02	0.05	0.44	—	1.12	—	39.0	0.30	23.8	241 228
CaSi + TiO ₂ ..	2.91	2.10	0.81	1.05	0.031	0.046	0.45	—	—	0.088	33.9	0.30	17.4	207 196
CaSi + TiO ₂ ..	2.89	1.90	0.99	1.61	0.026	0.049	0.44	—	—	0.32	31.75	0.27	18.8	228 218

² "Ladle Metallurgy," J. H. Williams, *Foundry Trade Journal*, December 17, 1942.

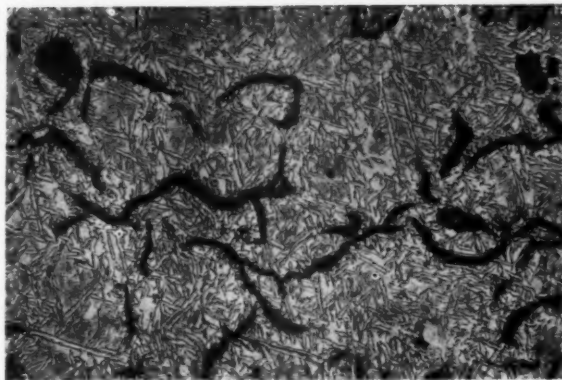


Fig. 1.—Etched structure—acicular iron.
× 300.

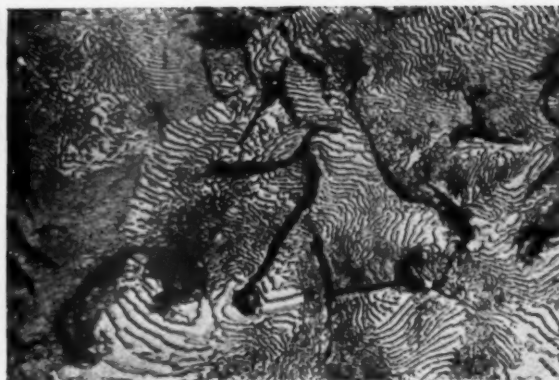


Fig. 2.—Etched structure—high-duty pearlitic iron.
× 600.

calcium silicide alone, and the enhanced effect obtained by the use of molybdenum additions. The structural character of these irons was of the type now often referred to as acicular. The addition of tungsten and titanium oxides instead of molybdenum is accompanied by a substantially poorer effect upon the test results. In fact, it would appear that these two latter oxides, added in this manner, can be looked upon as poisons, poisoning the effect of the calcium silicide. Incidentally, whilst the yield of molybdenum in the final metal was good, efficiencies up to 97% being obtained, the yields in the case of the other two oxides were poorer. In the case of tungstic oxide the maximum yield was 60%, with an average of about 40%, and in the case of titanium oxide the average yield was as low as 15%, with a maximum yield of 39%.

Acicular Cast Irons

The development of the high-strength cast irons, spoken of as "acicular-cast irons," has been referred to previously. Considerable work has been done by United States' investigators (e.g., Flinn and Reese⁵) in the study of the characteristics and properties of these irons. The "acicular structure," illustrated in Fig. 1, and compared with a typical structure of a high-duty pearlitic iron in Fig. 2, is described as consisting of needles of ferrite in an austenitic matrix. A British patent⁷ emphasises the importance of the process used in the production of these irons, the alloying constituents of which are molybdenum and nickel. The use of late additions of silicon play an important part in their successful production, and the composition casting temperature, pouring time and rate of cooling require to be correlated to ensure satisfactory results. The results of an investigation into the adoption of inoculation technique to the manufacture of austenitic cast irons have been made available by Eash.⁶ His conclusions are as follows:—

(1) The transverse properties and tensile strength of 2.25% carbon austenitic iron, containing 14% nickel, 6% copper and 2% chromium were markedly improved by ladle additions of ferro-silicon, whereas high carbon iron of similar alloy content was only moderately affected. The Izod impact properties of all grades were improved by silicon inoculation.

(2) The improvement in properties was associated with a corresponding change in the microstructure. Low properties existed in irons having a dendritic carbide and graphite arrangement, whereas high-quality material possessed a more random distribution of these constituents.

(3) Dendritism was most apt to form in low-carbon irons and at the surface of all castings; therefore it follows, naturally, that the elimination of this condition would improve the properties which are dependent upon a good structure in these locations.

(4) Austenitic nickel-copper-chromium cast iron made from charges with high percentages of steel had superior mechanical properties, and were improved to a greater extent by inoculation treatments than were castings made from cast-iron scrap.

(5) In general, the mechanical properties of the inoculated bars decreased as the carbon plus silicon increased.

(6) The austenitic nickel-copper-chromium cast irons possessed outstandingly high toughness and transverse ductility compared to pearlitic grey iron.

A great deal of investigation work has been undertaken with the object of understanding the mechanism of the effect of inoculants by investigators both in the United States and elsewhere. It is felt, almost intuitively, that their effect is in some manner associated with the way in which the graphite and the matrix structure forms on solidification. Norbury, in Great Britain, D'Amico and Schneidwind and Eash, in the United States, have studied the influence of under-cooling and observed various differences in the behaviour of irons coinciding with the production of different types of graphite. Attention has also been directed to the possible importance of the effect of dissolved gases, particularly hydrogen. The whole subject is packed with unanswered questions. It is, however, fortunate that practice does not need to wait for a full explanation of these obscurities.

Impact Testing Cast Iron

The importance of the impact test applied to cast iron has been recognised for a long time by foundry metallurgists and engineers. A Sub-Committee of the Technical Advisory Panel to the Directors for Iron Castings of the Ministry of Supply have been engaged for a

⁵ Flinn and Reese, *Trans. A.F.A.*, 1941.

⁶ Eash, *Iron and Steel*, May, 1943.

⁷ British Patent No. 545,102. Mond Nickel Co.

considerable time in the study of existing methods developed for the impact testing of cast iron and has carried out a great deal of experimental work in co-operation with industry. Whilst the Sub-Committee is not yet in a position to recommend the standardisation and specification of an impact test, they are able, as a result of their work, to recommend a procedure to be adopted in making the impact test of cast iron.

After considering all available methods the Sub-Committee felt that the most generally useful test would be a single blow test, and carried out in the Izod impact test machine owing to the availability of this type of equipment in many engineering works, and its acceptance as a standard method of test on other materials. As detailed below, however, a special form of test-bar is

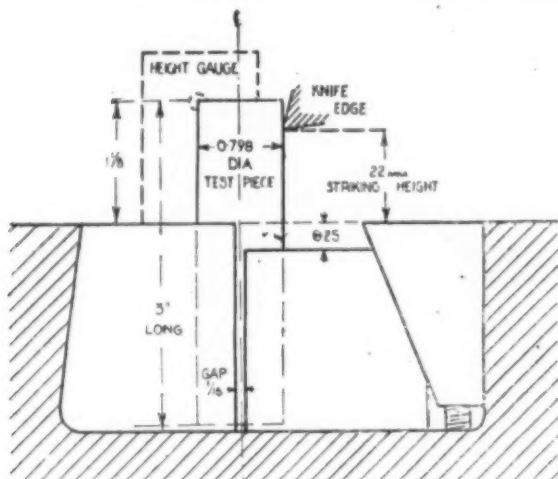


Fig. 3.—Arrangement of test-piece in Izod impact machine.

necessary in order to give a wide spread of results with adequate differentiation between different classes of cast iron. The 10-mm. square bar as used for the Izod test for steel is clearly unsuitable as the test figures generally lie between $\frac{1}{2}$ and 4 ft.-lb. With the test as proposed, the range of results is widened to between 5 and 70 ft.-lb. for modern grey-iron castings. It must be emphasised at the outset that the test is designed primarily for plain and alloyed grey cast iron, and is not suitable either for malleable cast iron or for the special highly alloyed irons of the austenitic types.

Details of Procedure

The procedure recommended for the impact test is as follows:—

(1) The impact test should be carried out in the standard 120 ft.-lb. Izod impact machine.

(2) The form of test-piece to be a 0.798-in. diam. plain bar, with no notch or groove. A separate test-piece to be employed for each test.

(3) The test-piece to be held in grips or dies in accordance with Fig. 3 herewith. This, it may be noted, is, with minor modifications, in line with the practice developed and recommended by the British Cast Iron Research Association following their own study of this problem.

(4) A striking height of 22 mm. to be employed, this height to be measured from the top of the rear grip, as indicated in Fig. 3.

(5) Special attention must be given to the fit of the grips in the machine, and the fit of the specimens in the grips. This calls for care in finishing the specimen accurately to diameter.

(6) Wherever possible, at least three tests on any one material should be taken and averaged.

(7) Test-pieces may conveniently be machined from the 1.2-in. diam. by 21 in. long transverse test-bar, or, alternatively, from the broken halves of this bar after transverse testing. In taking test-pieces, clearly the top end of vertically cast bars should, if possible, be avoided.

Spectrographic Analysis of Cast Iron

The application of the industrial spectrograph in the routine analysis of steels, aluminium and non-ferrous alloys is well known. It is also within the knowledge of a number of foundry metallurgists that in several industrial laboratories in the United States, and in Germany, the spectrograph has been in use for a number of years in the routine analysis of cast iron. The first description of the application of this apparatus to cast iron in this country was given at the annual conference of the Institute of British Foundrymen in June this year by Mr. J. Arnott and his colleagues at Messrs. G. J. Weir, Ltd., Glasgow.⁸ Of the constituents present in cast iron, carbon, phosphorus and sulphur cannot be estimated by these methods. Silicon, manganese, nickel, chromium and molybdenum have been estimated within certain ranges, and there is every reason to expect from analogy with steel manipulation that vanadium, titanium, aluminium and traces of other accidental elements can be tackled. The advantages and limitations of spectrographic analysis are summarised by these investigators as:—

(1) *Speed and Reduction of Labour.*—Once the conditions are established, routine samples can be run through quickly, taking spectrograms of, say, a dozen samples in duplicate on each plate. Each sample may contain five elements which are to be estimated. The preparation, exposure, development, etc., are the same, no matter how many elements are to be estimated, the only difference is the few additional minutes at the microphotometer.

As a rough idea of the overall time involved, a single operator averaged 2½ hours for nine samples of cast iron. In these silicon, manganese and nickel were estimated in duplicate. This gives a time for each duplicate estimation of under 6 minutes. This was done without any attempt to cut the time to the minimum, and the allocations for some of the operations were very generous. With two operators the time can be very much reduced. Apart from capital costs the only outlay is that for plates and developer. With 12 samples on a plate the cost per sample is under 2d.

(2) *Sample Easily Prepared.*—There is no need to drill; hence the hardness of the sample does not matter.

(3) *A Permanent Record is Obtained.*—At any time a plate may be looked out and measured for some element not originally checked.

⁸ "The Spectrographic Analysis of Cast Iron" Ling, McPheat and Arnott, I.B.F. Conference, June 26, 1943.

The disadvantages or limitations cover the following:—

(1) The method can only be applied to the estimation of elements whose log-ratio curves have been determined. For maximum accuracy, the curves should have been determined from standards of roughly the same type as those to be examined.

(2) There is a distinct top limit to the amount of an element which can be determined. These limits have not been explored, but it is doubtful if silicon in excess of 3% can be estimated with reasonable accuracy.

(3) The area which is sparked is so small that unsatisfactory results are obtained from non-homogeneous samples. If the homogeneity of the samples is in doubt, recourse must be made to the composite spark method.

(4) The method as at present practised is not applicable to drillings.

Melting Cast Iron

The importance of the conservation of fuel in all foundry operations, in addition to that of melting cast iron, is receiving special attention.

At the invitation of the Ministry of Fuel and Power the Council of Ironfoundry Associations, with the active co-operation of the British Cast-Iron Research Association and the Institute, established the Ironfounding Industry Fuel Committee in October, 1942. The Committee is composed of three representatives of the British Cast Iron Research Association, with Mr. J. G. Pearce as chairman, and three representatives of the Institute, whose acting secretary is honorary secretary of the Committee. Mr. W. J. Driscoll, B.Sc.(Eng.) (Associate Member), of the British Cast Iron Research Association, has been appointed full-time Fuel Officer. Since the formation of the Committee 14 regional panels have been formed corresponding with the regional areas of the Ministry of Fuel and Power. The branches of the Institute have been intimately associated with the formation of these regional panels, and in many cases the honorary secretaries of the Branches of the Institute of British Foundrymen have been appointed secretaries of the regional panels.

The work of this Committee is considered to be of the utmost national importance during the war, and will no doubt greatly assist the industry towards more efficient operation in post-war years.

In the melting of metal for the production of grey, white and malleable castings the foundry industry of to-day has available a wide range of melting furnaces. It is still true, however, that the cupola furnace is the most widely used, and for this reason any proposals for the modification and improvement in its design and operation are of first-rate importance to the industry. Details of experimental work in the design and operation of a basic lined cupola have been made available during the year in a paper by Mr. Renshaw, of the Ford Motor Company.⁹ The possibility of being able to obtain conditions of effective desulphurisation has drawn attention to the basic lining of cupolas on many occasions. By the use of a monolithic lining of stabilised dolomite suitably prepared for ramming, and the availability of a stabilised dolomite cement suitable for patching

purposes, the practical difficulties in constructing a basic-lined cupola were overcome. Stabilised dolomite has become available in recent years by the development of a successful method of preventing its hydration in storage.¹⁰ The experimental melts were planned to cover mixtures suitable for grey irons, malleable iron and converter steel, the percentages of steel scrap in the various mixtures being progressively increased from 20 to 100% throughout the series. The results obtained in these experimental melts demonstrated the practical character of the basic lining, and that not only could the sulphur pick-up be offset but under suitable conditions of operation the metal could be desulphurised below the charged composition. The process was operated on a full-scale production unit melting low-carbon metal for supply to an electric furnace. It was stated that the furnace was regularly operated to produce metal with a 50% lower sulphur content than was obtained with an acid-lined furnace and, when required, final figures of between 0.030 and 0.050% sulphur could be obtained. Whilst over 3,000 tons of metal had been melted in this production cupola, and the experience was very promising, it was considered too early to give an accurate refractory consumption figure.

Moulding Technique

No consideration of the developments in moulding technique can afford to neglect the important improvements in the applications of risers and feeder heads to the production of sound castings. The proper use of risers or feeder heads presents a problem which continually taxes the ingenuity of the foundrymen. The size, position, type and number vary with every new job, and must be determined before a satisfactory casting can be made. Each different casting is a problem in itself. An aspect of risering sometimes overlooked is that in addition to being essential to obtaining internal soundness they also greatly increase the cost of the finished article. The size of risers may vary from 10% to as much as 70% of the total casting weight. Except for a few basic principles the layout of risers on any casting is still very much a matter of "rule of thumb," but considerable attention has been directed to recent improvements in the technique of employing "blind risers." Blind risers may be defined as the use of risers which do not extend through the cope, but are completely surrounded by sand and may be placed at any point within the mould. Whilst this is not a new development, the appreciation of the importance of the atmospheric pressure on the action of blind risers has had an important effect upon the principles embodied in this technique. Taylor and Rominski, in their paper before the A.F.A. in June, 1942,¹¹ regard a United States patent (No. 2,205,327) by John Williams, dated June 18, 1940, as the earliest publication dealing with the part played by atmospheric pressure in the technique of "blind risers." This subject is too large to be dealt with in the scope of this article, but it is strongly recommended that the paper by Taylor and Rominski, and others which have appeared since, should be consulted.

On the subject of moulding articles the publication of the second report of the Moulding Materials Subcommittee of the Steel Castings Research Committee,

¹⁰ "Dolomite Bricks for Use in Steel Works," Swinden and Chesters. Iron and Steel Institute, 1941.

¹¹ "Utilising Atmospheric Pressure in Making Steel Castings," Taylor and Rominski. *Foundry Trade Journal*, October 15, 1942, et seq.

⁹ "Basic Cupola Process for Desulphurisation," Renshaw. *Foundry Trade Journal* June 24, 1943.

in November, 1942,¹² and a study of British resources of steel moulding sands in June, 1943,¹³ are of particular interest to those interested in the ironfoundry. The second report contains considerable information on clay binders and core compounds, and the details of sands and synthetic sand mixtures, primarily of interest to the steel founder, are worthy of more than a passing glance from the ironfounder.

In a paper by Roxburgh before the annual conference of the Institute of British Foundrymen certain aspects of the technique in the production of malleable castings were fully described. The use of synthetic sand, the gating and feeding, including special reference to the spherical type of feeder, were dealt with in addition to many details of the methods of moulding.

Institute Activities

Amongst the important activities of the Council of the Ironfoundry Associations the establishment of the Ironfoundry Industry Fuel Committee and the C.F.A. Education Committee has taken place during the year.

¹² Second Report, Moulding Materials Sub-Committee, Iron and Steel Institute, November, 1942.

¹³ "British Resources of Steel Moulding Sands," Davis and Rees. Iron and Steel Institute, June, 1943.

Further Developments in the Production and Technology of Magnesium and its Alloys

(Continued from page 84).

primarily as paint bases than as protective treatments in themselves. This is of particular importance in the storage of magnesium alloy parts, since it is generally inconvenient to paint them until immediately prior to assembly. Chromate coatings alone may be insufficient protection and the additional application of lanoline or an equivalent grease is recommended.

Applications

As mentioned previously in this article, the shortage of metal in Great Britain for aircraft engineering applications has led to the replacement of some magnesium alloy parts by aluminium alloys in aircraft construction, and it is likely that the proportion of magnesium alloys used in British war-planes is less than that in both German and American planes. This magnesium shortage no longer exists.

The continued examination in this country of magnesium alloys in captured or crashed German aircraft has revealed several interesting facts, the chief of which is probably the extensive use of magnesium alloy forgings, particularly for such parts as supercharger impellers.

Schmidt,²¹ reporting the results of an examination conducted in the laboratories of the Dow Chemical Co., of magnesium parts from a Messerschmitt ME-110 and a Junkers JU-88 plane has commented on the extensive use of forgings by the Germans. The more important forgings were the engine mounts, dive brakes and supercharger impeller. Other magnesium parts on these two aeroplanes were found as sand and die-castings, extrusions and sheet and the alloy compositions used were magnesium-aluminium-zinc and magnesium-manganese types. The Germans used a high percentage

In each case these activities have the full co-operation and support of the Institute of British Foundrymen and the British Cast-Iron Research Association.

The Institute of British Foundrymen was able to hold its 40th annual general meeting and conference in London. Its Technical Committees reported continued activity, and all the branches have been able to maintain full schedules of programmes. The British Cast-Iron Research Association established in its new headquarters and laboratories at Alvechurch, the premises being officially opened during the year by Lord Riverdale, continues its work with unabated vigour. The publication of the Board of Education's White Paper, relating to the planning of post-war education, has provided an opportunity for the foundry industry to give consideration to the problems of foundry education. The foundry degree course in the Faculty of Metallurgy at Sheffield University, the British Foundry School, and proposals for training in foundry craftsmanship are having the serious attention of the Education Committee of the foundry associations and technical bodies in addition to the problems associated with the supply of foundry apprentices.

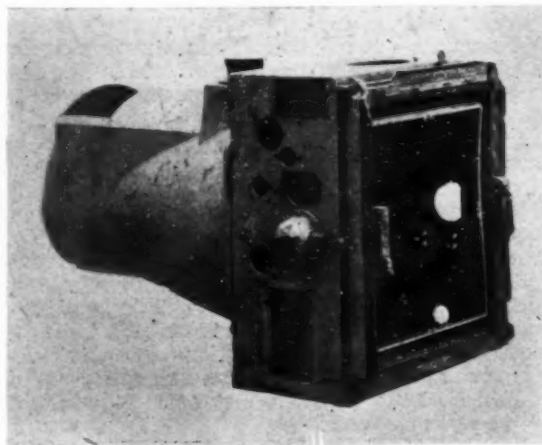


Fig. 6.—Magnesium alloy camera case taken from crashed German aircraft.

of the castings in the as-cast condition and only the more important castings were used in the heat-treated condition. Among other magnesium parts mentioned and illustrated in Schmidt's article are:—Cast covers for crankcase and rocker box, air-intake manifold, cowl flap control ring, supercharger intake and housing, cam drive and camshaft covers, landing wheels and gear, fuel tank brackets, rudder track parts, pilot seats, tachometer drive, oil strainer and scavenger pump.

Hanawalt,²² also of the Dow Chemical Co., has stated that about the same amount of magnesium is used in aircraft construction in Germany as in the U.S.A., and in about the same types of parts; there are as many as 850 lb. of magnesium castings in a modern bomber.

The largest magnesium alloy casting made to date in the U.S.A. is a pump base weighing 900 lb.

²¹ H. W. Schmidt. Paper presented at the 11th annual meeting of the Institute of Aeronautical Sciences, January, 1943. 14 pp.

²² J. D. Hanawalt. Discussion at joint meeting of A.S.M. and A.I.M.M.E., Detroit, March 1943; A.S.M. Review (U.S.A.), April, 1943, 16 (4), 7.



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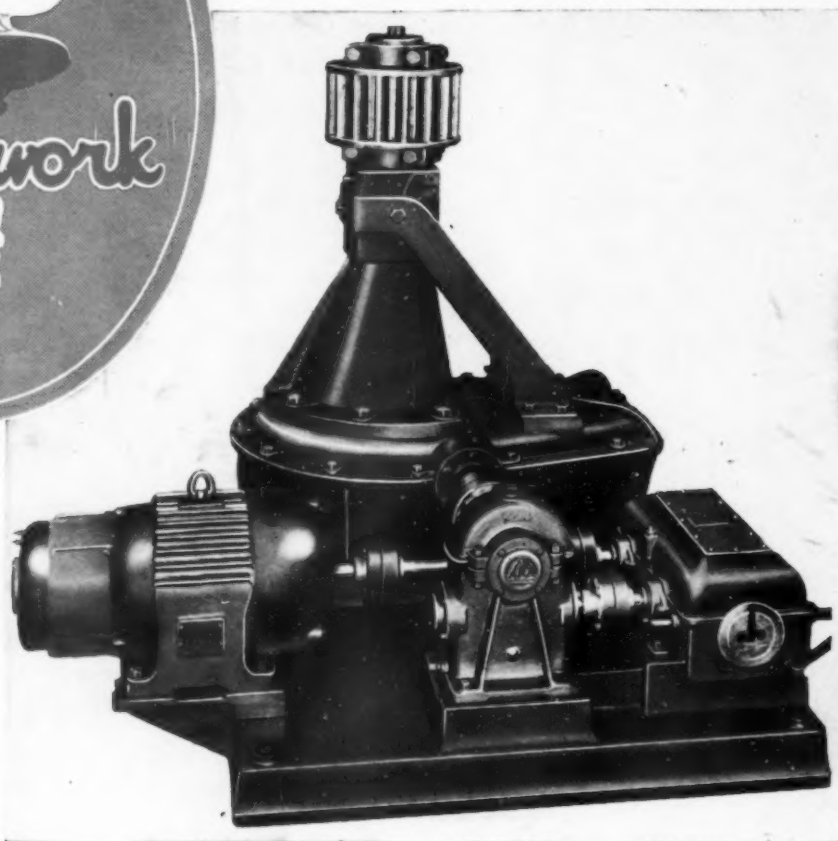
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Alternatively — if you think the conditions need it — use two thermocouples: one in the load and one in the atmosphere, and note the relation of their readings.

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6. With electric furnaces, make sure the contactor gear is operating freely and making positive contact. Check the insulation of the pyrometric equipment. Only the current from the thermocouple should reach the terminals of the instrument. Make sure the sheath of the thermocouple cannot come into contact with the heating element, and as an extra precaution, earth it.

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7. On gas-fired furnaces, check the movement of the valves, see that they are not becoming stiff through lack of lubrication, or the accumulation of foreign matter. The latter applies with particular force where dirty, or only partially cleaned industrial gases are burned. Check the valve settings for gas/air ratio control.

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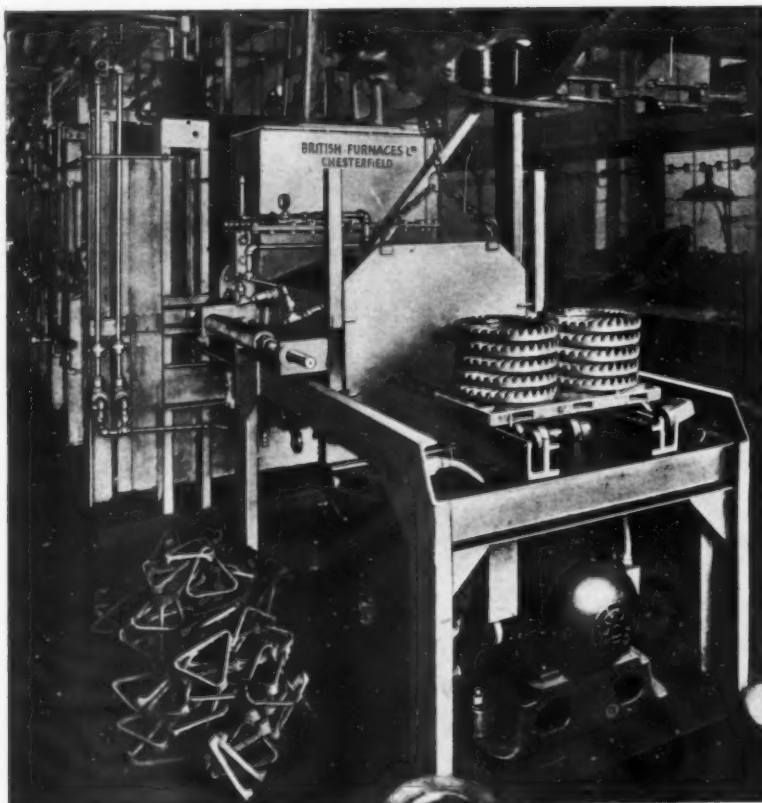
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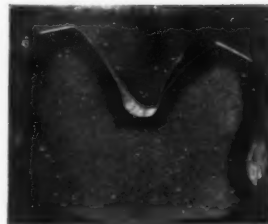
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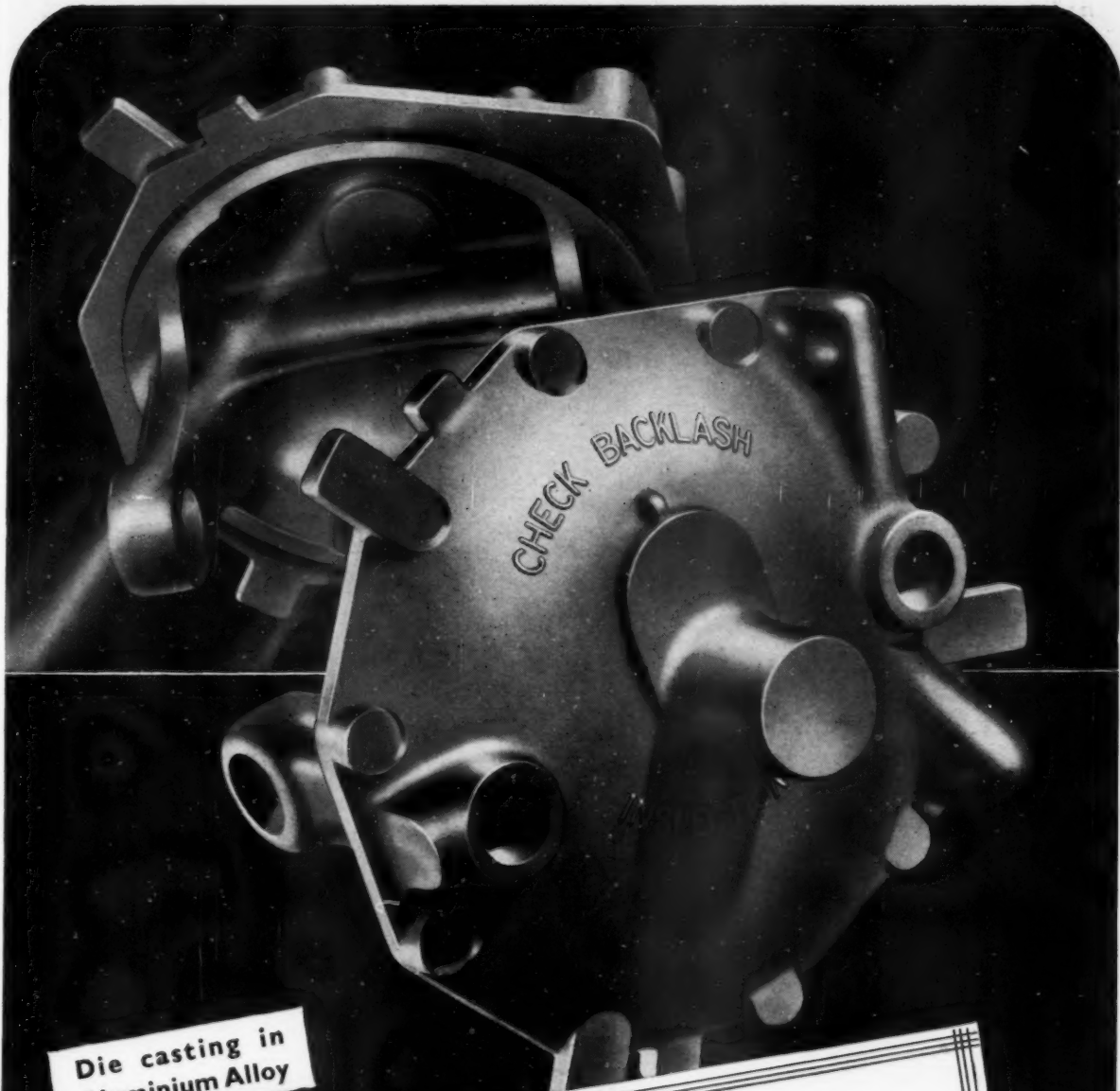


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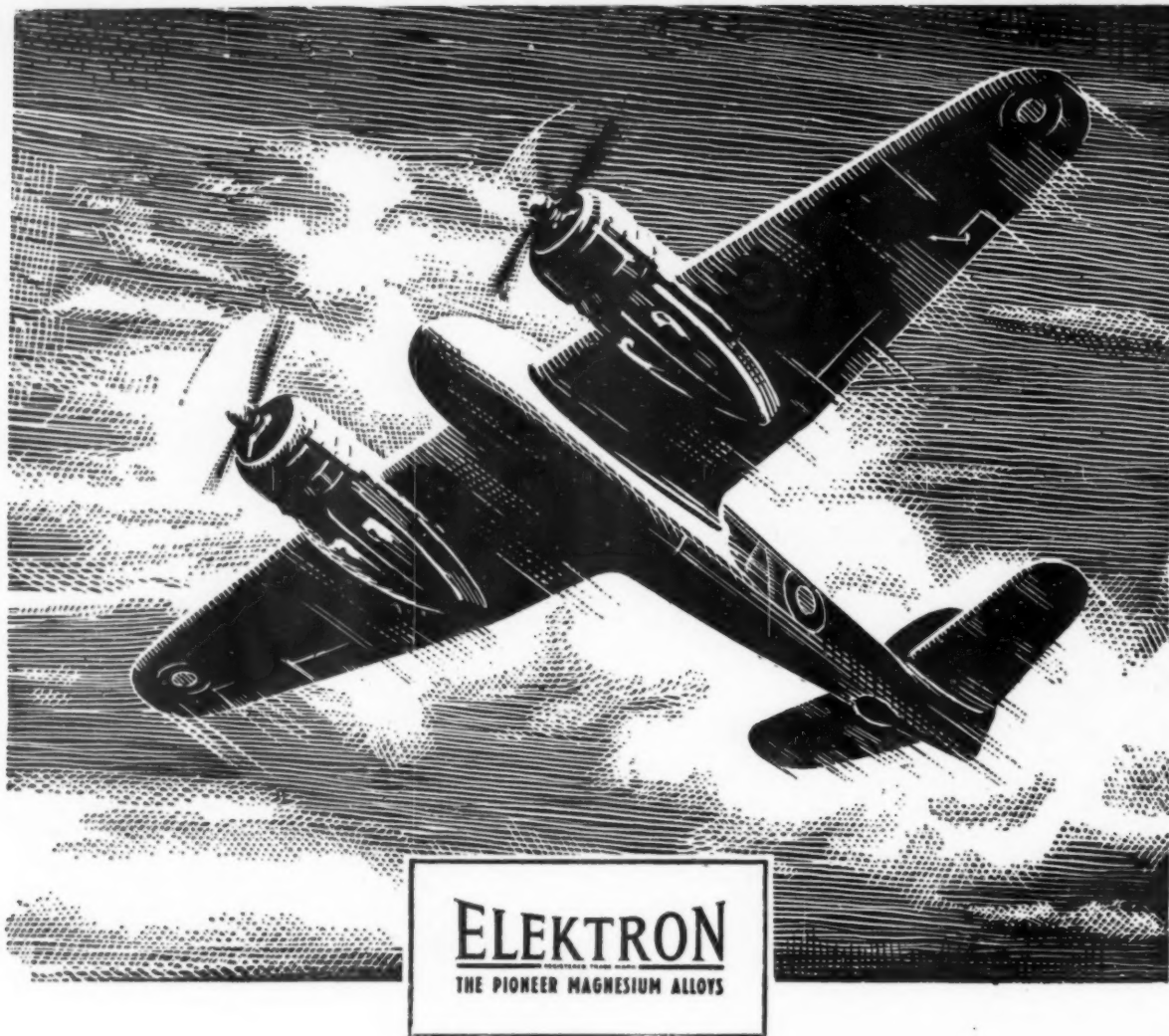
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The Weldability of Cast Iron*

By T. J. Palmer, A.M.Inst.W.

In this, the concluding part, the author deals with methods of joining cast iron where deep fusion of base metal does not occur, and it is shown that low temperature methods have certain inherent advantages over fusion welding. The weldability of "burnt" cast iron is discussed, and the present position of the processes under consideration is examined and the outstanding points relating to procedure are reviewed.

From an operational point of view the fusion welding of cast iron is very easy. With the part preheated to about 700° C., welding commences by directing the torch flame into the root of the fracture until the edges flow together. Penetration of weld metal must occur at the underside. The sides of the vee are then melted, the torch being moved about in such a manner as to form a continuous pool of metal between the edges of the two parts being joined. Filler material is added from the welding rod and well puddled in the metal fluid, with the object of surfacing sand or other impurities which might promote hardness, and similar undesirable features in the final joint. Finally, the top edges are flowed in and sufficient rod added to fill up the groove and provide adequate reinforcement. As the operation proceeds along the seam great care should be taken not to allow liquid metal to flow upon surfaces not hot enough to receive it, or "chilling" will take place. It is equally important for the rod to be well inserted into the melt, and not added in drops; metal deposited in such a manner is not only oxidised, but can form a primary cause of hard spots and porosity in welded joints. In fusion welding a miniature casting is being formed, and the art of the welder involves the use and adjustment of a technique designed to produce a sound casting. Blowholes, hard spots, etc., are a result of failure on the part of the operator to satisfactorily control his cast.

Welding completed, the article is covered and protected from draughts. It is an advantage to reheat to a fairly uniform temperature, after which the whole is

allowed slowly to cool. According to the nature of the casting, cooling is spread over a period of time sufficient to eliminate strains, and to make quite certain there is no difficulty in subsequent machining operations.

A cast-iron fusion weld is very strong, generally stronger than the base metal itself; the fineness of graphite distribution in the weld, as compared to that of the adjacent parent metal, is partly responsible for this. Except alloyed cast irons where relatively large percentages of special elements figure in the analysis, the different cast irons which are encountered do not vary much as regards their weldable characteristics. If anything, ferritic irons are more difficult than those which are nearly or completely pearlitic. This appears to be the case if the silicon content of the iron is high and the graphite structure very coarse. It might be logical to assume, therefore, that any increased difficulty may be due to the inferior foundation for welding provided by large graphite flakes.

Low-Temperature Welding

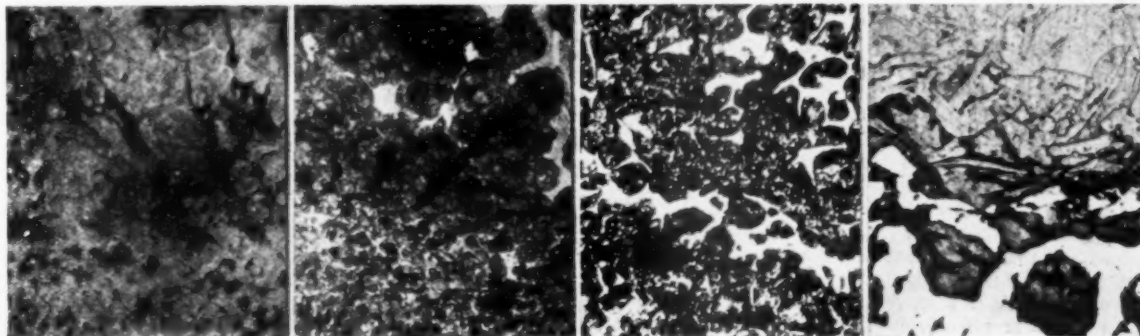
The low-temperature welding of cast iron can be defined as a process offering some of the advantages of fusion welding without many of its attendant disadvantages. The process is sometimes claimed to be new, but it is doubtful if this is actually the case. Many welding operators had practised the technique before the improved alloy iron rods, now employed specifically for the purpose, were made available; indeed success in the application of this method does not appear to hinge so much upon the use of any specially modified filler rod as upon the employment of a searching

Fig. 15.—Junction of weld and parent metal. Ordinary cast-iron welding rod deposited by low-temperature technique.

Fig. 16.—Junction of weld and parent metal. Special alloy cast-iron rod deposited by low-temperature technique.

Fig. 17.—Effect of using high-phosphorus rod for low-temperature welding.

Fig. 18.—Intergranular penetration of bronze into parent metal.



* Continued from November issue.

and easy-flowing flux. Ordinary welding rods of the type required for fusion welding have been used with success, though the specially prepared rods mentioned above are superior for many purposes. Low-temperature welding consists essentially of heating the base-metal edges to about 850° C. and then flowing a cast-iron rod over the heated surfaces. During welding the parent metal is not melted at all; in this, and certain other respects, the process is very similar to that of bronze-welding. A fairly strong bond is developed, and the joint possesses the valuable property of almost perfect colour match. Low-temperature welding methods possess certain inherent advantages over fusion welding and their value, as a means of joining cast iron is becoming increasingly realised. In fact, the importance of deep fusion in welding has at times been exaggerated, and the question arises, from the very attractive properties of joints made by low-temperature methods, as to whether these views have been in all cases justified. Certainly there is a leaning towards the use of methods whereby welding is performed at temperatures below the melting point of the metal being joined, not only with cast iron, but with other metals and alloys. The benefits derived from welding cast iron by the low-temperature technique can be summarised:—

Lower operating temperatures, which brings about less volume change throughout the welding cycle; this, in turn, reduces the risk of cracking and distortion.

Faster welding speed.

Less tendency for producing hard spots, or zones.

Lower heating and operating costs.

Less skill required to effect the weld.

The photomicrographs in Figs. 15 and 16 are representative of welds made by the low-temperature process, using a high-silicon unalloyed rod and a special alloy cast-iron rod, respectively. The bond is clearly not one of deep fusion, but one in which the line of demarcation takes the form of almost a straight line—a distinguishing feature of this process.

Procedure for Low-Temperature Welding

No special preparatory methods are required for low-temperature welding beyond those already given for fusion welding. Preheating is necessary, and this may be either partial or full, according to the type of casting: a temperature ranging from 400°–450° C. is sufficient in many cases. The filler metal generally recommended is a close grained special alloy cast-iron rod which contains a small proportion of nickel. High-phosphorus rods are definitely bad; they can cause a hard and brittle constituent to be deposited at the weld junction (Fig. 17).

A flux is required, and to obtain the best results a specially prepared flux paste is used; this is applied to the work after the latter has been lightly heated. This forms an easy-flowing protective layer over the metal surface and overcomes the ill-effects of oxide formation. When the joint is one of a surface bond oxides, unless removed, can prove particularly troublesome.

There is nothing unusual about the actual welding technique. A torch of normal power is held at a fairly flat angle to the work, and the metal raised locally to a temperature of about 850° C. (bright red). The end of the welding rod is then melted, when it should spread out and cover effectively the neighbourhood directly

under the torch flame. As the welding flame is moved forward and about to prepare further areas for the reception of weld metal, the melt is allowed to proceed easily forward. Stirring or puddling with the rod, which is necessary in fusion welding in order to expel base-metal impurities, is not required in low-temperature welding, since the base metal is not melted. The added metal is moulded as required, and as many runs as thought necessary are deposited. The result is a sound and very firm bond.

After welding, the usual precautions are observed as the metal cools down to ordinary temperatures.

Bronze-Welding

Bronze-welding, which is a true low-temperature method, needs no introduction, since the process has been used as a means of repairing cast iron for some considerable time. The method is especially useful for repairing castings of intricate shape, and for other purposes where it is important to keep heat input down to an absolute minimum. There is less likelihood of cracking occurring in bronze-welding than in either of the two methods just described, due to the lower working temperatures employed. In addition, high local stresses developed during cooling are more favourably accommodated as the relatively high plasticity of bronze, which is retained at quite low temperatures, imparts an element of ductility not normally associated with welded joints in cast iron. There are, however, two important disadvantages connected with this process. In the first place the 60/40 Cu.-Zn. base-filler rods used are of a different colour, and have properties quite unlike those of cast iron; its use as a means of reclaiming faulty castings, or for any other purpose where identical colour match is required, is, therefore, out of the question. Secondly, the physical properties of bronze-welding rods do not permit the operation of welded joints at elevated temperatures. Joints made by bronze-welding are really very strong—at least as strong as the average type of cast iron.

Because bronze filler rods melt at a temperature some 300° C. below that of cast iron the process is essentially one of non-fusion. The bond is developed by intergranular penetration and by tinning. Solid solutions are probably formed, and there is a definite locking effect due to penetration of bronze along the graphite flakes and in surface cavities (Fig. 18). The bond takes place in almost a straight line (Fig. 19), and the structure of the parent metal remains unchanged throughout the operation.

Preparation for welding cast iron by the bronze-weld method requires a certain amount of care if good results are to be obtained. The types of joint mostly employed for repairing fractured parts are similar to those used for fusion and low-temperature welding, but the grindstone must not be used for final operations as the metal surface is then covered with a film of graphite. This prevents the formation of a sound bond, and also makes welding difficult. Metal where bronze is to be deposited must be really clean, and this is effected either by filing, chipping, or sandblasting; emery cloth or sandpaper must not be used. Parts are thoroughly degreased, and castings which contain appreciable quantities of coarse graphite should have this removed by a process of surface oxidation or the bond will not develop satisfactorily.

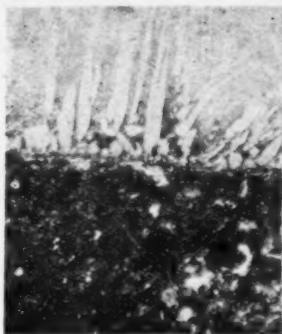


Fig. 19.—In bronze-welding—a surface welding process—the bond takes the form of almost a straight line.

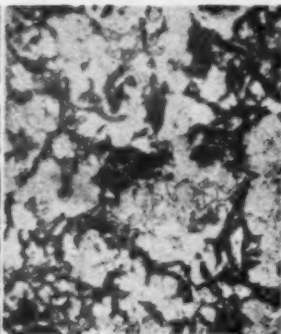


Fig. 20.—Burnt cast iron.

Preheating is carried to a black heat only (400° – 450° C.), and in many cases this can be applied locally. A powder flux, mixed into a paste with water, takes care of oxides and impurities, and at the same time increases the fluidity of the melt. The filler rod for general work is a 60/40 brass containing silicon for deoxidation purposes, and minor amounts of toughening and hardening elements. High-nickel rods are more suitable where a deposit of greater hardness or strength, or where closer colour match is required. The use of a slightly oxidising flame has been found advantageous for the bronze-welding of cast iron.

To make a weld, a tip of small power locally heats the already warmed metal to a temperature of about 700° C.; the addition of filler rod should then cause the metal surfaces to be "flooded" with a layer of bronze. Overheating produces unbonded areas, but underheating will cause sluggishness of flow and a bond which is lacking in tenacity. If the operating temperature is correct, and the joint nicely prepared, the molten metal will flow along steadily and will effectively cover and adhere firmly to the cast-iron surface. The necessary build-up of bronze should be obtained in a single pass, if possible. Any difficulty in producing a satisfactory joint in cast iron by bronze-welding is usually a result of failing to carry out correctly the preliminary operations already outlined.

Except with "difficult" castings a greater latitude in cooling speed after welding is permissible with bronze-welding than with any other welding method; moderately slow cooling is in order in the majority of cases.

The Weldability of Burnt Cast Iron

Fatigued, or burnt, cast irons do not, as a rule present an easy problem for the welder, though they are frequently encountered. "Burnt iron" is usually defined as that which has operated at temperatures in excess of about 500° C. for fairly lengthy periods of time. Furnace parts, for example, come within this category, and microscopic examination of such components reveals evidence of structural disintegration. "Grown" graphite flakes and intergranular penetration of oxides for some considerable depth are a feature of the irons under consideration (Fig. 20). Obviously a metal of this type does not offer a sound background for welding by any process or method, and the result is generally a bond of inferior quality. Bronze-welding, which relies

to a large extent upon surface penetration is useless, and, in any case, would be unsatisfactory at the high temperatures prevailing in their subsequent operation. Fairly satisfactory results can sometimes be obtained using the low-temperature technique, if the part is not too badly oxidised; fusion welding is probably the best way of dealing with burnt iron, however.

All loose scale is removed before welding, and the surfaces near the joint are cleaned. A copious supply of flux is used, and the melt very thoroughly worked with the welding rod—the only chance of success hinging upon the ability of the operator to sufficiently dilute the heavily contaminated metal to form a weldable base, after which the process will be made easier. Full or semi-fusion (low temperature) methods can then be employed to build up the required deposit. Very thin metal sections, and also parts which have been exposed to elevated temperatures for extremely long periods of time, are frequently so badly oxidised as to make welding by any method impossible. The thickness of the scale or crust is a useful and fairly reliable indication as to the internal condition of the iron, and when this is considered excessive, in proportion to the metal section, the part should be rejected, as the chances of making a satisfactory joint by welding will be small.

Summary

In deciding upon the most suitable welding process to employ for joining a part made of cast iron, the usefulness of the three gas-welding processes which have been discussed, namely, fusion welding, low-temperature welding, and bronze-welding must be assessed both in the light of their adaptability for the work in hand and also upon the ability of the operator to apply them in making the repair. Economic considerations will weigh heavily against fusion welding in certain cases; in others it may be the only means of making a satisfactory repair. Attention is directed especially to the newer methods in the case of repairing parts which are intricate in shape, or where excessive distortion or scaling is particularly troublesome. Colour characteristics of weld and mother metal alone are frequently the sole deciding factor when bronze-welding may not be used. Neither can bronze-welding be employed for joining burnt or fatigued cast irons, or those which are subsequently to operate at temperatures above 300° C. With heat-treated irons fusion welding cannot be used if the metal is to retain the improved properties induced by that heat-treatment. Whatever the welding method, care is necessary when dealing with these irons as their structures are unstable at relatively low temperatures.

In preparing the work cleanliness of the metal edges is important, especially with bronze-welding, and a good-quality flux is essential in all cases. In fusion welding the selection of a rod which is externally clean, and of proper analysis, cannot be over-emphasised if hard spots, slag and porosity are to be avoided. Some degree of preheating is nearly always necessary, but for "normal" castings becomes less important when employing low-temperature methods.

Except with bronze-welding, cooling rate after welding will largely determine the hardness of the finished joint and its surroundings, and to ensure a machinable deposit, and at the same time to relieve internal stresses, retarded cooling must be employed. Prolonged cooling is particularly necessary with castings which are tied in any way.

The joining of cast iron has been simplified as a result of the improved and more versatile filler rods now available from firms who have made a scientific study of the process, and every effort should be made to see these products are used for the purposes intended. The importance of cast iron in engineering has forced attention upon methods of joining this ancient metal, and

operators should be properly versed in the present methods applicable. Though in a number of cases cast-iron parts are being replaced by fabrications in steel, the process is a gradual one, which in itself has its problems, and cast iron, as we know it, is likely to enjoy popularity for some time to come. Its brittleness is largely responsible for the wide field at present open to welding.

The Equilibrium Diagram of the System Aluminium-Zinc

THIS is the first of a new series of publications which the Institute of Metals proposes to issue in response to the need which it feels to exist for up-to-date versions of the equilibrium diagrams of certain binary alloy systems. Each of the series will consist of (a) the diagram reproduced on a generous scale, and based on what is regarded by a competent critic as the most reliable work in each phase-field; (b) a table giving all important data connected with the diagram; (c) a number of critical notes; and (d) a list of references. The next alloy systems to be included in the series will be copper-tin, copper-zinc, and copper-aluminium.

By G. V. Raynor, M.A., D.Phil. (Institute of Metals Annotated Equilibrium Diagram, Series No. 1). $11\frac{1}{2} \times 8\frac{3}{4}$ in. Pp. 4, with 1 figure. 1943. London. The Institute of Metals, 4, Grosvenor Gardens, London, SW. 1 (6d. post free).

Personal

Mr. T. Watson has been appointed to the Board of Directors of General Refractories, Ltd., Sheffield. Mr. Watson joined the company in 1929, and since 1931 has held the position of commercial manager.

Mr. A. G. E. Briggs has been appointed a director of English Steel Corporation, Ltd. Educated at Oundle and Sheffield University, he served his apprenticeship at Vickers Works, Sheffield, and was subsequently on the sales staff at the London office of Vickers, Ltd. Early in 1933 he was appointed sales manager of English Steel Corporation at Sheffield, and became a special director in 1935. At the beginning of the war he was loaned to the Ministry of Supply and is now Deputy Controller of Iron and Steel Supplies.

Mr. H. H. Burton, chief metallurgist and special director of English Steel Corporation, Ltd., and director of the Darlington Forge, Ltd., has been appointed a director of English Steel Corporation, Ltd. Educated at Sheffield Royal Grammar School, King Edward VII School, and Sheffield University, Mr. Burton has a wide experience in the investigation of metallurgical problems, and was appointed chief metallurgist of English Steel Corporation, Ltd., in 1935. During the war he has been associated with many of the technical committees set up by the Ministry of Supply, including the Iron and Steel Technical Committee, the Technical Advisory Committee on Special and Alloy Steels. Early in 1943, he visited the United States of America as a member of the Ministry of Supply's Metallurgical Mission to confer with representatives of the War Production Board on the problem of alloy conservation.

Electromagnets, Ltd.

DEVELOPMENTS of the above Company have necessitated larger works and offices, in consequence of which the new address to which future correspondence to this Company should be addressed is No. 1, Bond Street, Hockley, Birmingham, 19.

The British Aluminium Company, Ltd.

THE above Company's temporary head office address is now Salisbury House, London Wall, London, E.C. 2 (entrance from Circus Place). Telegraphic address: "Cryolite, Ave., London." Telephone: CLerkenwell 3494 (Private Branch Exchange). The offices of the Company, at Shrewsbury, Shropshire, and at Marlborough Court, 68, Pall Mall, S.W. 1, have been closed. Other address—London depot, Park Avenue, North Circular Road, N.W. 10; Birmingham, 3, Lansdowne House, 41, Water Street; and Leeds 3—66, Kirkstall Road—will be unchanged.

A Vocational Guide

THE Institute of Export has recently published a small booklet, under the above title, which is designed to bridge the gap, until H.M. Stationery Office is in a position to republish the series of "Choice of Career" pamphlets designed to indicate in a general way the fields of employment open to those leaving school. The present guide is not intended to provide a complete list; it is in fact mainly limited to organisations within the professions which have some connection with the conduct of international trade. It includes a list of some examination bodies which have been able to continue examinations during the war period. Copies may be obtained from the Institute of Export, Royal Empire Society Buildings, Northumberland Avenue, London, W.C. 2.

The B.T.L. Bulletin

WE have received Bulletin No. 12, published by Baird and Tatlock (London), Ltd. The object of this publication is to place before laboratory workers in the sciences and applied arts the latest developments in laboratory equipment in order to facilitate the adoption of the more recent methods in laboratory technique. The Bulletin, comprising 24 pages, deals with a wide variety of subjects associated with laboratories. Since the war, owing to paper restrictions, it has only been possible to publish issues at rather long intervals, and it is probable that the present issue will be the last while the war continues; interested readers are therefore advised to obtain a copy for reference purposes. It is published by Baird and Tatlock (London), Ltd., "Halidon," Claremont Lane, Esher, Surrey.

MICROCHEMISTRY

APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

DECEMBER, 1943

METALLURGIA

101

CHEMISTS will have noted with approval the recent decision of British chemical ware manufacturers to take steps to ensure that Britain shall lead in the production of instruments and apparatus. This decision represents a step forward which is of particular importance for micro-chemists, who have been faced with many irritating anomalies in the supply of special apparatus. It must, for example, be well known that many microchemical balances normally only weigh up to 10 g. Yet anyone who has tried to purchase a British-made absorption tube for carbon-hydrogen micro-determinations will be very definitely of the opinion that precise specifications should be laid down which would discourage the manufacture of 12 g. tubes. What would we think of the shop-keeper who sold us a pair of scissors with the melancholy apology, "I'm afraid they won't cut very well, but you may be able to bore holes with them." Many of us mightn't want to bore holes, in any event.

The manufacturers have shown their willingness to co-operate. It is now up to the microchemists to ensure that the manufacturers are given every help in producing the apparatus which is required.

Electrographic Analysis

By David L. Masters, M.Sc., Ph.D.

Electrographic methods, which are described, have been applied to show the presence and distribution of specific constituents in metals, minerals and other conductors of electricity. Ingenious adaptations enable the methods to give a rapid and valuable answer in quite complicated circumstances.

THE branch of analysis known as electrography is of comparatively recent growth. Because it is most easily applied to metals and alloys—although it has been used also with minerals which conduct electricity easily, and with biological sections, it should be of considerable interest to metallurgists in particular. Unfortunately, however, much of the literature which has appeared on this technique is in journals which are not readily available to the general run of chemists. It, therefore, seems that some account of the method and of the range which it covers would be of considerable interest.

The electrographic method may be said to be a direct and logical outcome of what may be referred to, for want of a better term, as the contact print method. This was used a considerable number of years ago for the detection and location of sulphides in iron alloys.¹

If a piece of such alloy, suitably prepared, was pressed on to a sheet of photographic paper which had previously been soaked in dilute sulphuric acid, the regions containing sulphide were attacked, giving off sulphuretted hydrogen. This evolved gas in turn attacked the silver in the photographic emulsion, so that blackened portions of the photographic paper formed, in effect, a sort of map of the distribution of the sulphide throughout the section of alloy. It was easy to form this map into a permanent print by fixing it in hypo according to normal

photographic procedure. The method was extended to cover other alloys in which it might be desired to observe segregation, and such materials as sections of minerals.

It is, of course, apparent that while such a test could be extremely useful, it might not always be possible to ensure a perfect print. Some method which would ensure that the material which was being sought would without fail be carried on to the testing surface was desirable, and the obvious answer was to apply an electric current in such a way as to carry ions of the material into solution and on to the surface at a point close to its original situation in the test sample.

Such a scheme was proposed independently by two workers, Glazunov² and Fritz.³

Expressed in the simplest terms, the technique put forward by them consists in transferring ions from the surface of a sample on to an absorbent medium such as paper, using an electric current to achieve the transference. The ions are then detected by the colours which they give with reagents applied to the absorbent medium either before or after the process of electrolysis.

Electrographic Apparatus

In essence, a simple apparatus consists, as shown in Fig. 1, of a base-plate A, which is made either of aluminium or of some non-conducting material which has a

² *Chimie et Industrie*, 1929, **21**, 2, 425; *Chem. Zentr.*, 1930 (II), 1104 1932

(1) 1398.

³ *Z. anal. Chem.*, 1929, **78**, 418.

¹ Baumann. *Metallurgie*, 1906, **3**, 416.

thin sheet of aluminium fixed to its upper surface. In either case, a terminal B is attached. On this base-plate is laid a sheet of absorbent paper C, which is moistened with a suitable electrolyte, such as potassium chloride or potassium sulphate solution. This is followed in turn by yet another sheet of absorbent paper D, which carries the reagent or reagents. Then the specimen E is placed on top, with the face which it is desired to test resting on D. The whole is pressed together by another metal plate F, which bears a second terminal G.

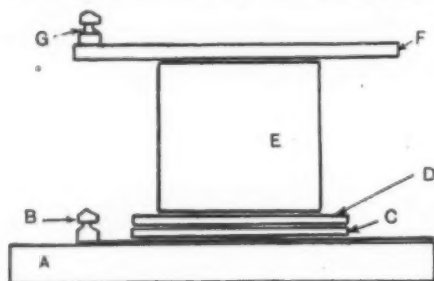


Fig. 1.—Basic arrangement of electrographic apparatus.

The terminal B is the cathode and the terminal G the anode in what amounts to an electrolytic cell which is operated by a small battery of dry cells. Yagoda⁴ recommends a battery capable of delivering 22.5 volts, which should be connected in series with a variable 500 ohm resistance and a milliammeter.

Various modifications of this basic apparatus have been suggested from time to time. In the type shown in Fig. 2 close and even contact between the test face of the sample and the reagent paper is achieved by interposing a thick paper pad C, while under the specimen a layer of felt or sponge rubber covered with aluminium foil A forms the base. (The lettering of the various portions corresponds to that in Fig. 1.) Pressure is applied by the 500 g. lead casting F, which runs on two vertical pillars, and the whole is mounted on a wooden base H, which has a groove lined with lead foil or aluminium foil K, the latter carrying the terminal B.

A highly developed apparatus has been described by Hermance⁵ which has a special press, in which the specimen is mounted for test. A control panel is fitted with rheostats for controlling, and a voltmeter and ammeter for measuring the current which is used in a test, and there is also an automatic time switch which controls the duration of the passage of current. The apparatus in a simplified form, which can be used as a portable instrument, has also been described by the same author.⁶

Test Media

The actual "reagent paper" may vary considerably. Absorbent paper is usual for the simpler type of work, where it is not necessary to take into account the very fine structure of the pattern recorded. Obviously, fine structure will be lost against the fibre background of such paper. The only precaution which is necessary here is to use a fairly hard paper which will not shrink much on drying. Non-waterproof Cellophane has been proposed as an alternative, which has advantages in

certain cases, but it must always be remembered that Cellophane, on wetting and drying, shrinks considerably. This may to some extent be overcome by a preliminary treatment with water and drying.

Photographic paper and photographic plates and films have a very wide use. As we have seen earlier, the earliest type of work from which electrography developed used

reagent "papers" of this nature. However, unless the silver in the photographic emulsion is going to serve some useful purpose in the test (as for the sulphide, already described) it must first be removed. This is achieved by hypo, and at the same time it is advisable to harden the gelatine by a

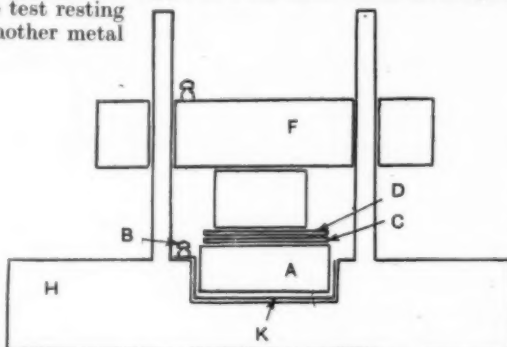


Fig. 2.—One of several modifications of the basic apparatus.

chrome alum bath. Both these media are highly satisfactory, since the gelatine provides what is, in essence, a structureless surface which is capable of revealing extremely fine structure in the electrographic pattern. Of the two, the plates and films are perhaps rather better, since, being transparent, they may be projected in a lantern, or examined under a microscope, in order to observe the pattern more carefully. The only means of doing this, in the case of the paper, is to use a microscope with a vertical illuminator, or a projector, such as an epidiascope.

An ingenious medium has been suggested by Yagoda.⁷

This, which was developed by the author for use with patterns from biological tissues, can be applied in other cases. It consists of a thin sheet of plaster of paris, which is prepared in a specially designed mould so as to have smooth surfaces and a thickness of about 1 mm. Such a sheet is translucent enough to be examined by transmitted light, and is fine-textured enough to permit examination of fine structure. Two interesting points about these sheets may be noted. In the first place, since they are prepared by the user, they may contain any insoluble reagents desired, since these may be mixed in during the actual manufacture of the plaster. (On the other hand, paper must be impregnated either with reagents which are soluble, or which have been rendered insoluble after they have entered the fibres in a soluble form.) Secondly, the plaster sheets do not need the addition of an electrolytic solution to carry the current, since, merely by moistening, a dilute solution of calcium sulphate which is a good enough conductor of electricity is produced.

Mode of Testing

Yagoda has shown that in fairly homogeneous materials subjected to an electrographic test, the ions deposit according to Faraday's second law. Also, since in general it requires about fifty micrograms of a metal to produce a strong positive over one square centimetre of surface, an approximate measure of the current and

⁴ *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 125.

⁵ *Bell Lab. Record*, 1940, **18**, 269.

⁶ *ibid.*, 1940; **18**, 272.

⁷ *Loc. cit.*

time necessary to produce a strong electrograph can be determined from the law—

$$T I = 96,500 \frac{a K}{E}$$

where T = time in seconds, I = current in amperes, a = area of surface, E = equivalent weight of metal, and K = the amount (in gms.) necessary to produce a strong positive over 1 sq. cm., in the general case, 50μ g.

Let us suppose that in a copper test we are applying a current of 15 milliamps. Then our equation becomes as follows:—

$$T \times 0.015 = \frac{96,500 \times 50 \times 10^{-6}}{32}$$

This shows that a reasonable time for the application of the current would be 10 secs. Of course, this is only an approximation, but it will be found that with this as a basis, it will be possible rapidly to arrive at a final time. In any case, it is not advisable to use exposure times longer than 30 secs.

Having determined a probable time, the precise mode of registering the pattern must be decided. Two broad procedures are possible. The reagent may be deposited directly in the paper, and consequently as soon as current is passed, the ions will indicate their presence by alteration of the reagent. Alternatively, the ions may first be trapped in an inert medium, and subsequently developed by use of appropriate reagents. Each of these has its appropriate spheres. It is obvious that if the reagent is soluble, it may not be as satisfactory to use it until after the ion has been deposited. On the other hand, if the ion is taken up by the paper in a soluble form then it will tend to give an inaccurate picture of the location of the material unless it is immediately fixed in position. Each case must, in effect, be judged on its merits, and often preliminary experiments will be required in order to determine which of two procedures will give the best results in any specified case. An example of the former procedure is the detection of nickel, which can be done by direct impregnation of the paper with an alcoholic solution of dimethyl glyoxime. This is not removed to any extent by the electrolyte applied during the determination, and likewise the nickel precipitate is insoluble, so that very detailed prints are obtained. To illustrate the latter procedure, a test for iron may be instanced. This is of use when metals other than iron, which form insoluble hydroxides, are present. The electrographic print is taken, using paper soaked in dilute ammonia solution, which therefore accepts the iron as insoluble ferric hydroxide. If the print is then immersed in a solution of potassium ferrocyanide, which is slightly acid, the iron is converted into the bright blue complex which is unmistakable. Incidentally, this test is one of those in which the use of Cellophane is preferable to that of gelatine papers, since there is not the same tendency of the blue colour to "run" when it is embedded in the Cellophane.

Having, then, decided on the length of the test and the precise way in which it is intended to indicate the ion sought, it only remains to fit the apparatus together, pass the current for the appropriate time, remove the reagent paper, which may either be washed and dried direct in the first procedure, or, in the second, washed and developed, then washed free from developing solution and dried.

Examples of the Technique

Up to the present the descriptions have been confined to straightforward tests which do not demand any ingenuity. However, it is possible to extend the uses of electrography far beyond tests of this nature. This is best illustrated by a number of examples, since a wide variation is to be found.

The electrograph can give very valuable results when examining coatings of one metal on another. Thus, Hermance⁸ has examined articles which have been plated first with nickel, and then with chromium. He used paper which had been impregnated with both barium hydroxide and dimethyl glyoxime. When the current was passed, the chromium, converted to chromate, formed insoluble yellow barium chromate. The nickel formed the red nickel complex. Thus a print in red and yellow showed without any doubt the location of the platings.

Minerals containing copper, nickel and cobalt have been investigated by a single test.⁹

After taking up the ions by electrographing on to gelatine-coated paper impregnated with fairly strong ammonia, the development is carried out with saturated alcoholic dithio-oxamide. In this way the copper region is indicated by a dark green stain, the nickel by blue, and the cobalt by brown.

The plaster of paris sheets described earlier have been recommended by Yagoda for the determination of lead distribution. Since the electrolytic solution which the sheets supplies itself, calcium sulphate, will immediately fix the lead as the highly insoluble lead sulphate, it is only necessary to develop the lead afterwards, say with sulphuretted hydrogen, in order to obtain a highly accurate record.

Chloride in plant tissues has been determined by Yagoda¹⁰ by an interesting conversion method. The pattern is received on photographic paper which has been freed completely from silver halides, and then impregnated with silver chromate. (In actual practice it is better to get the silver-halide-free paper from a photographic manufacturer.) The chloride ion is then electrographed (with reversed terminals, since now we are dealing with an anion) on to the paper, where it is held as the more insoluble silver chloride. By washing with dilute nitric acid, the unconverted silver chromate is removed, and subsequent reduction to metallic silver shows up the original location of the chloride.

Other recent uses which have been found for electrography are in the rapid detection of gold in bulk metal,¹¹ in plating,¹² and the detection of molybdenum in alloy steels.¹³ In this last example, a graphite cathode is used instead of the more usual metal one.

It will be seen from this brief summary of the elements of electrographic analysis that the method is capable of numerous applications in the hands of chemists who deal primarily with metals. While the qualitative and distributive information that may be obtained from it is of the first importance, it should not be overlooked that it is highly probable that some sort of semi-quantitative data might also be obtained at the same time. In this connection, it is, of course, necessary to remember that the behaviour of any particular ion will be affected

⁸ Loc. cit.

⁹ Yagoda, loc. cit. Feigl. "Qualitative Analysis by Spot Tests" 2nd Ed., 1939.

¹⁰ Ind. Eng. Chem., Anal. Ed., 1941, 12, 698.

¹¹ Calamari, Hubata and Roth. Ind. Eng. Chem., Anal. Ed., 1942, 14, 535.

¹² Lerner. Ind. Eng. Chem., Anal. Ed., 1943, 15, 416.

¹³ Calamari, Hubata and Roth. Ind. Eng. Chem., Anal. Ed., 1943, 15, 71.

to a greater or less extent by the nature of the material surrounding it. Thus, it would be wrong to interpret the amounts of copper, indicated in a test where copper was, say, a minor constituent in a mineral, by reference to preliminary tests carried out using pure copper, or brass as controls. The amount of copper deposited will almost certainly be entirely different in the two cases, and, if the mineral is not a reasonably good conductor, may, in the extreme case, be nil. But leaving aside extremes of this nature, there is no doubt that by careful

control of the time and amount of the current used, electrographic analysis can be used to give some indication of the amount of a particular ion, much more readily than would be the case using the more usual methods of analysis. In fact, one of the great appeals which the technique must have is the speed with which it can be induced to give results. These few remarks, in conclusion, may serve to indicate a field which would be worth investigating to a greater extent than it has been up to the present.

Sub-Micro Analytical Technique

ANALYTICAL chemists nowadays recognise the existence of semi-micro and full micro methods, which are often referred to in more precise terms as centigram and milligram analysis. It is not so widely known, however, that a third branch exists, in which much useful pioneering work has been done by Benedetti-Pichler and his co-workers.¹ This is the sub-micro technique, or, conforming to the more specific nomenclature, microgram analysis.

Benedetti-Pichler and his collaborators have investigated the possibility of analysing qualitatively quite complicated microgram samples, and have also kept an eye to the semi-quantitative estimation of these samples. Since they have found that the limit of identification of some tests which they have investigated is as low as 10^{-13} — 10^{-14} g. of ion in 10^{-9} — 10^{-10} ml. of solution, it is obvious that the extension of ordinary qualitative tests to sub-micro work is quite feasible.

It is, of course, obvious that a highly specialised technique is demanded. In the first place, while working with fractions of a cubic millimetre of solution the rate of evaporation must be combated by some such method as working in a chamber with an artificially moist atmosphere, or in a film of oil. Then, all operations and observations are carried out under the low-power microscope, and some sort of micro-manipulator is required. Solutions are transferred by specially constructed pipettes which, in their turn, are operated by a hypodermic syringe arrangement. It is even possible to carry out distillation of from 0.1 to 0.01 of a cubic millimetre of liquid using capillary cones.

Tests are carried out on an ingenious condenser, made from a drawn-out glass rod, and which has a cross-section on its working surface, of about 0.07 sq. mm. The condenser uses the principle of internal reflection to concentrate a light beam on this tiny platform.

These workers have investigated the separation and identification of the commoner members of analytical groups I and II. Silver, mercury, lead, bismuth, copper, cadmium, arsenic, antimony and tin have all been shown to be amenable to the technique, even in relatively complicated mixtures.

As an instance of the possibilities of the technique, a particle of Woods' alloy of about 1 microgram in mass was subjected to a complete analysis. This was completed in approximately 12 hours of working time, which may, at first sight, seem rather long. But, on consideration of the technical difficulties which must be overcome to handle the minute amounts of precipitate, this time is not really excessive.

All the elements present were detected and identified. Semi-quantitative estimates were made, with the

following results:—Present, 0.5 μ g. bismuth, 0.2 μ g. lead, 0.125 μ g. tin, 0.125 μ g. cadmium. Found, 10 μ g. bismuth, 0.4 μ g. lead, 0.1 μ g. tin, 0.1 μ g. cadmium.

In all the semi-quantitative work, reasonable co-ordination between the amounts present and the amount found has resulted, except with bismuth, where the estimation depends on the volume of bismuth hydroxide, which is gelatinous, and of cadmium, as the sulphide. Other ions are reasonably satisfactory, and it is extremely likely that one or other of the modifications suggested may improve these two difficult cases.

It is only to be expected that this work will be extended by degrees to the other analytical groups, so that, as the technique is altered and improved, we will become accustomed to the somewhat spectacular analyses of this calibre.

Specification

THE problem of the precise specification of micro-chemical apparatus, which has been discussed elsewhere in this section, has received much more attention in the United States of America than it has here. A sub-committee set up by the Division of Analytical and Micro Chemistry of the American Chemical Society has been at work along these lines for some years, and two reports have been issued by that committee. These reports lay down the detailed requirements for the apparatus used in some microchemical estimations which require close control: the estimation of carbon and hydrogen and the Dumas estimation of nitrogen,¹ and the estimation of sulphur and halogens.²

Full scale drawings accompany the reports, and doubtless these will be of very great help to any body which endeavours to confer similar very necessary benefits on the microchemists of this country.

The Microchemical Balance

The same Division of the American Chemical Society has a sub-committee dealing with microchemical balances, and this has recently published a report which gives much food for thought.³ In order to arrive at a figure which could be proposed as a specification for reproducibility of weighings, a wide range of balances (29) was tested for the standard deviation and the probable error, using 1 g. and 10 g. weights.

The committee expresses surprise at the poor performances of many of the balances thus tested, a deviation of as high as 22.3 μ g. being recorded in one case. As a consequence, it is urged that every analyst who uses a micro-chemical balance should test this instrument by the method described, in order to determine the quality of its performance.

¹ *Ind. Eng. Chem., Anal. Ed.*, 1937, **9**, 483; 1940, **12**, 233; 1942, **14**, 813; 1943, **15**, 227.

² *Ind. Eng. Chem., Anal. Ed.*, 1941, **13**, 574; 1943, **15**, 476.

³ *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 230.

⁴ *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 415.

Protection Against Caustic Embrittlement by Co-ordinated Phosphate pH Control

By T. E. Purcell and S. F. Whirl

CAUSTIC embrittlement manifests itself either as leaks or cracks at the riveted seams, rivets, tube ends, and flange connections of evaporators, boilers and digesters, or less frequently as an explosion of the entire pressure vessel. To distinguish it from previously identified forms of cracking due to time temperature, stress and fatigue, the phenomenon was called "caustic embrittlement"—caustic, because one of the early investigators believed caustic soda to be the controlling factor of the cracking. Further research disclosed that embrittlement cracking is predominantly intergranular and occurs only when steel,

demonstrated that the concentrated solution in contact with the steel must contain at least 75,000 p.p.m. (1.85 mols. per L) NaOH and 1,600 p.p.m. (0.026 mols. per L) SiO_2 for the characteristic cracking to develop at temperatures between 200° and 300° C.

An extensive programme of embrittlement testing was begun in 1938 with a newly developed detector apparatus for testing the embrittlement characteristics of boiler waters in the field. Using this device, a total of 55 tests have been conducted on boilers operating at pressures from 175–440 lb. per sq. in. In no case, where the test was of three months or more duration, did the A.S.M.E. ratios give protection against caustic embrittlement. Several other inhibitive treatments

operation. A radically different approach to the problem resulted in the development of the co-ordinated phosphate-pH control method of protection against embrittlement.¹

As measured by the results of embrittlement detector tests the treatment is effective; no specimens failed when the conditions required by the co-ordinated phosphate-pH control method were examined, even when the test was extended to six months.

The test apparatus used was that described in detail by Schroeder, Berk and O'Brien.^{2, 3} Installed on an operating boiler, it supplies all but one of the factors necessary for embrittlement. The steel is stressed to the yield-point, the boiler water is concentrated by slow evaporation to the atmosphere, and the concentrated water is in contact with the stressed steel. The only remaining factor is the boiler water. Consequently, the detector is of particular value in studying chemical treatment as an inhibitive measure against embrittlement.

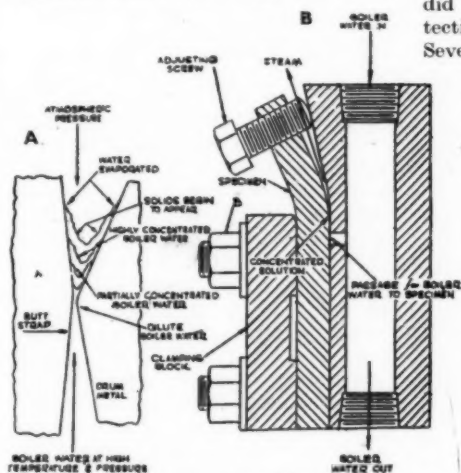


Fig. 1.—(A) Greatly magnified diagram of a leak, showing concentration mechanism that detector duplicates. (B) Details of embrittlement detector and its method of operation.

stressed to the yield-point, is immersed at elevated temperatures in solutions containing both caustic soda and silica. In recent laboratory tests it has been

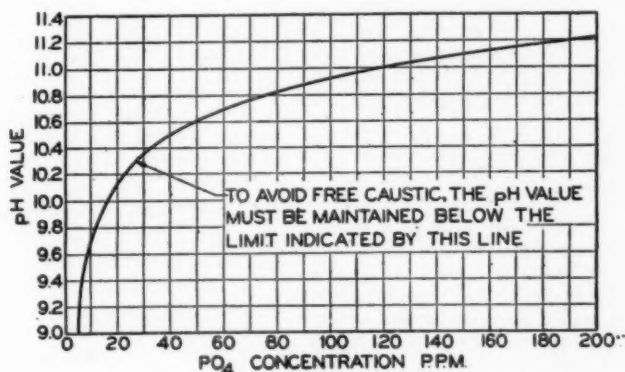


Fig. 2.—Relation of pH value to trisodium phosphate concentration.

were tried and while some of these appeared to be effective protectors they possessed properties that proved unsuitable to the operating procedures and control practices. It was also evident that none of the inhibition treatments would be satisfactory for the 1,000 lb. per sq. in. boilers then under construction and since placed in

In order to achieve the concentration of chemicals necessary for embrittlement, the boiler water must be

¹ From Paper presented at 83rd General Meeting of the Electrochemical Society, April, 1943. (Preprint 83-25.)

¹ T. E. Purcell and S. F. Whirl. "Embrittlement of Boiler Steel: Experiences with the Schroeder Detector." *Trans. Am. Soc. Mech. Engrs.*, **64**, 397 (1942).

² W. C. Schroeder and A. A. Berk. "Intercrystalline Cracking of Boiler Steel and Its Prevention." *U.S. Bur. Mines Bull.*, p. 38 (1941).

³ W. C. Schroeder, A. A. Berk, and R. A. O'Brien. "Intercrystalline Cracks in Locomotive Boilers." *Rly. Age.*, **100**, 25-28 (1940).

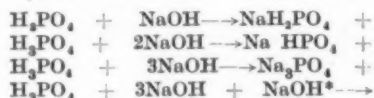
concentrated in a manner analogous to that of Fig. 1A. Water slowly leaks between the drum metal and the butt strap. The heat of the metal and the liquid will cause evaporation of the water toward atmospheric pressure to result in a concentrated solution.

The essential details of the embrittlement detector are shown in Fig. 1B. The apparatus not only simulates the leakage of a boiler seam, but also accelerates the attack to yield results in a relatively short time. That the attack is greatly accelerated is known from experience, since boilers which leak have been known to operate for many years without failure. The findings of Bardwell and Laudemann⁴ with different treatments on locomotive boilers indicate that the detector results may be used reliably to predict actual operating experience.

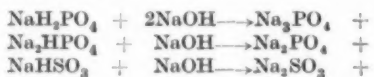
The theory of the co-ordinated-pH method of protection against caustic embrittlement is that in the absence of caustic there can be no caustic embrittlement. The fundamental principle, therefore, is to produce a boiler water which will not deposit caustic on evaporation (either in the detector or at a leaking seam in a boiler) and yet maintains sufficient alkalinity for general corrosion inhibition. This is accomplished by maintaining in the boiler water phosphate alkalinity only, no caustic alkalinity being present. In this manner, the boiler water is rendered non-embrittling, since any attack will necessarily be limited to the relatively weak action of the phosphate salts as contrasted with that of sodium hydroxide. This treatment must not be confused with the unsuccessful use of trisodium hydroxide.

The graph shown in Fig. 2 is the basis of control. It was formulated by determining the pH of a series of solutions prepared with reagent grade trisodium phosphate and water having a conductance of less than 1 microhm. The pH was determined by the hydrogen electrode, using a Leeds and Northrup metre. By plotting the pH value and the PO_4 concentration of the boiler water on this graph, it can be readily ascertained whether or not the boiler water contains caustic alkalinity. A point which falls on the curve indicates that all phosphate exists as trisodium phosphate (Na_3PO_4); a point which falls below the curve shows the presence of acid phosphate salts; a point in the region above the curve is evidence that caustic is present. From another point of view,

the PO_4 -pH co-ordinates merely represent some stage in the neutralisation between phosphoric acid and sodium hydroxide, as exemplified by the following equations:—



Eq. 3 is associated with the curve of Fig. 2; both indicate that all the phosphate exists as trisodium phosphate; combinations of Eq. 1, 2 and 3 yield-points below the curve, while Eq. 4 with excess sodium hydroxide yields a point above the curve. The excess may be eliminated by Eq. 1, 2 and 3, or, if solid chemicals are preferred, NaH_2PO_4 and Na_2HPO_4 may be used. These react according to Eq. 5 and 6.



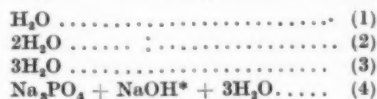
In case sulphite is used as an oxygen scavenger, sodium acid sulphite may be effectively used to reduce the pH without disturbing the PO_4 concentration. The reaction is given by Eq. 7. The use of phosphoric acid is particularly recommended where the feed water is alkaline or contains carbonates, which break down at boiler temperature to yield "free" sodium hydroxide. Any other mineral acid may be similarly used to reduce the alkalinity of either the feed water or the boiler water without increasing the phosphate concentration. During the tests carried out caustic soda, trisodium phosphate, disodium phosphate, and sodium hexametaphosphate were freely used to maintain the desired pH- PO_4 co-ordinates.

As a result of the tests carried out on specimens of cold-rolled S.A.E. 1020 or 1112 steel, and hot-rolled boiler flange quality steel at pressures of 275 to 440 lb. per sq. in., the author concludes that in no case where the test was of sufficient duration did the A.S.M.E. ratios protect the specimens against failure. Sodium chloride was also found to be ineffective in conjunction with the A.S.M.E. ratios at 420 lb. per sq. in.

The effectiveness of the co-ordinated phosphate pH control method for the prevention of embrittlement is demonstrated by nine tests of from 67 to 188 days' duration, in which not a single specimen failure was experienced. The duration of the test period was found to be very important. On the author's

boilers any evidence of non-cracking in less than 90 days might lead to false conclusions with respect to protective treatment.

The conventional and accepted



methods of analysis for caustic (hydroxide alkalinity) are not satisfactory for low concentrations. A modification of the Winkler procedure using strontium chloride and phenolphthalein indicator was found to give better results. The amount of hydroxide alkalinity that can be tolerated is very low. Therefore, the pH should be maintained below the curve of Fig. 2.

It is apparent that this method of



chemical treatment of boiler water is not restricted to the use of phosphate salts. Any thermally stable salt of a weak acid and a strong base could be utilised, the pH values being made to correlate with the concentration of the stoichiometrically neutral salt.

Bend Tests on Carbon Strip Steel

THE effect of chemical composition, amount of cold reduction and annealing time on the longitudinal flat bend characteristics of killed, fine-grained, plain carbon strip steels have been studied. Low carbon steels give flat bends free from visible cracks, irrespective of manganese content or amount of cold reduction prior to annealing. The region of grain coarsening between approximately 10 and 25% cold reduction prior to annealing, was clearly shown. Medium carbon steel requires at least 35% cold reduction to obtain satisfactory flat bends with minimum annealing times. Low manganese content also appeared desirable. High carbon steels cannot be bent flat around a radius of twice their gauge thickness and at least 45% cold reduction prior to annealing was necessary to obtain satisfactory bends under these conditions. Low manganese content and long annealing times appeared helpful in improving the material's response to the bend test.

* A. F. Sprankle and M. A. Hughes, *Trans. Am. Soc. Metals*, June, 1943.

Impact Strength of Steels at Low Temperature

THE notched-bar impact strength at +20, -80, and -180° C. of cast steel of the compositions given below was investigated in order to find a material having a minimum impact strength of 3 mkg. per sq. cm. in the temperature range considered. It was found that this specification could be met only with the use of the two austenitic Cr-Mn steels No. 12 and 13. Steel No. 2, containing 2% nickel, is seen to closely approximate to the minimum impact strength required;

while steel No. 1, with 3% nickel, is unsatisfactory at -180° C.

The addition of Cr (steels Nos. 5 and 6) proved without effect, and the Cr-Si-Al steels Nos. 7 and 8 proved even less suitable. However, the Cr-Si-V steels Nos. 9 and 10 exhibited high impact strength at -80° C. when tested in oil-quenched condition. Cr-Mn steel No. 11 alloyed with Mo and V proved disappointing even at -80° C. The tests show that oil quench secures a less steep drop in impact strength with decreasing temperature.

COMPOSITION OF STEELS.

Steel No.	C.	Mn.	Si.	Cr.	Ni.	Mo.	V.	Al.
1	0.2	0.62	0.40	—	2.91	—	—	—
2	0.16	0.66	0.42	—	4.91	—	—	—
3	0.19	1.36	0.37	—	—	—	—	0.36
4	0.20	1.53	0.45	—	—	—	—	0.59
5	0.17	1.55	0.38	1.05	—	—	—	0.67
6	0.17	1.25	0.41	1.97	—	—	—	0.13
7	0.17	0.6	1.07	0.97	—	—	—	0.03
8	0.18	0.67	0.99	1.14	—	—	—	0.41
9	0.15	0.62	0.96	1.03	—	—	0.18	—
10	0.17	0.55	1.04	0.93	—	—	0.40	—
11	0.16	1.28	0.43	2.6	—	0.11	0.16	—
12	0.18	15.2	0.86	12.0	—	1.1	0.61	—
13	0.28	15.15	1.4	11.4	—	1.19	0.62	T10-27
14	0.23	0.49	0.33	—	—	—	—	—

MECHANICAL PROPERTIES.

Quench Empl. yrd.	0.2% Y.P. Kg. per sq. mm.	Ultimate T.S.	Elongation, %	Reduction, %	Impact Strength, Kg. per sq. cm.			
					-20.	-40.	-80.	-180.
1 Oil	43.6	61.4	23.0	33	12.0 12.3	—	4.3	1.9
2 Oil	57.3	69.5	27.0	68	21.4 22.1	—	12.7 12.8	2.6 2.7
3 Oil	43.3	52.4	26.0	69	15.7 12.1	—	5.7	1.8
4 Oil	42.0	52.1	26.0	64	17.0	—	7.1	1.9
5 Oil	48.2	60.8	17.6	44	12.0	—	6.4	1.9
6 Oil	45.2	56.1	24.8	73	22.1 23.1	—	6.6 9.1	1.6 1.7
6 Air	41.6	55.4	27.6	69	20.3 21.4	—	8.4 11.1	1.3 1.6
7 Oil	40.7	55.2	26.0	71	17.4 19.8	—	1.3	0.4
8 Oil	43.4	60.9	24.0	38	6.7 6.8	—	1.7 1.1	0.5 0.4
9 Oil	49.0	60.2	25.0	71	17.7 20.0	—	9.4 9.6	1.6 1.7
9 Air	44.4	53.6	24.6	66	14.3 15.3	—	2.8 3.0	0.3 0.4
10 Oil	52.2	66.3	23.0	71	16.4 18.6	—	8.0 9.0	1.7 1.7
10 Air	46.4	60.4	22.6	71	16.0 17.2	—	3.9 4.9	1.4 1.6
11 Oil	45.8	60.6	23.2	79	15.4 11.2	—	2.8 3.0	1.6 1.7
12 Oil	30.5	74.6	36.0	38	11.2 17.9	—	11.0 11.0	3.5 4.0
13 Oil	31.8	75.0	34.0	36	15.7 18.0	—	9.0 10.0	4.0 4.4
14 Air	33.1	52.0	51.0	51	13.0 13.6	6.9 7.4	0.7 0.7	0.1 0.1

H. Jurecek and W. Trommer. "Impact Strength of Steel Castings at Low Temperatures." *Giesserei*, 30, 1943, p.21.

High Temperature Wear Resistance

LOW carbon steels, containing 0.04 to 0.0073% carbon, cast iron, high-chromium and chromium-nickel steels, and high-manganese steel have been investigated, with the aid of a special apparatus, for purely sliding metallic friction to determine the effect of heat in the range from -190° to +700° C., and with sliding velocities of 1.8 to 9.5 in. per sec.

Wear occurred in three different forms: (1) Formation of flakes; (2) carrying away of flow layers; and (3) oxidic abrasion. The first case caused high wear due to immediate contact and mutual reaction of the two metals sliding on each other. Increased heating reduced wear. Flow layers presuppose high temperatures in the outer layers of the two metals, either produced by the friction or supplied artificially. An oxide film almost always existed, if this was destroyed the wear was high and low if the flow layer moves under the intact oxide film and can escape at the side

* From *Arch. Eisenhüttenw.*, 15, 1942, 453-466.

Electrolytic Polishing of Zinc and Brass

By J. L. Rodda

CHROMIC acid has been used for many years as an etching reagent for zinc. Its action is customarily controlled by the presence of certain catalytic agents, of which sulphates and chlorides are examples, the quality of the etch and rate of attack being functions of the type and amount of the catalyst as well as the concentration of chromic acid. The oxidising potential of chromic acid is so high that even alloys of zinc and copper may be dissolved without the reprecipitation of copper which would occur with some reagents. Chromic acid has one peculiarity. Its solutions will not dissolve zinc except in the presence of a catalyst of the type mentioned.

If, however, the zinc or zinc alloy is made the anode, it will be attacked even in solutions of pure chromic acid. At certain current densities this anodic etching may be of use in identifying certain phases in the copper-zinc system. At higher current densities the action becomes one of polishing. Specimens of both rolled zinc and rolled brass (65/35) have been anodically polished in a solution of 200 grms. of CrO₃ to 1,000 cc. of

water, using platinum gauze as the cathode. In general, polished surfaces are produced on both metals at current densities of about 16 amp. per sq. in. (2.5 amp. per sq. cm.) or more, and frosty surfaces at lower current values. Lowering the temperature is slightly favourable to polishing. Brass polishes a little more readily than zinc. At extremely high current densities (60 to 80 amp. per sq. in. the surface tends to become pebbly.

Electrolytic polishing in chromic acid confers some resistance to tarnish-

ing. Buffed brass darkened much more rapidly on both outdoor and indoor exposure than electrolytically polished brass. After two years indoors anodically polished brass still retained its bright yellow colour, whereas buffed brass had a bronzed appearance. Whether the method is suited for commercial use or not is problematical. The high current density required is a drawback. This, however, is no bar to its use in preparation of metallographic specimens.

From Mining and Metallurgy, August, 19—3.

The Chemical, Physical and Mechanical Properties of Permanent Mould Grey Iron

By R. Schneidewind and E. C. Hoenicke

PERMANENT mould iron castings are of a modified grey iron composition cast into permanent air-cooled or water-cooled moulds. The microstructure after casting consists of eutectiform graphite, ferrite, and a small amount of pearlite. After annealing at 870° C. and cooling slowly through the critical range the matrix is completely ferritic. To determine the properties of such irons, which might be of assistance to engineers and designers, a series of tests were made of various physical and mechanical properties of permanent mould irons having an average composition of 3.52% total carbon, 3.41% graphitic carbon, 2.55% silicon, 1.01% manganese, 0.086% sulphur, and 0.215% phosphorus.

irons, on 0.5 in. diameter test-bars for the 0.875 in. section and on 0.375 in. diameter test-bars for the 0.5 in. section irons. Modulus of elasticity was determined from stress-strain diagrams. Both the tensile strength and modulus of elasticity are considerably higher than would be expected from material with a ferritic matrix and decrease as the section of the material increases. The Brinell hardness is about the same for all sections examined and compressive strength determined on cylinders having a height of twice the diameter decreases with increase in section.

Transverse tests on the 0.5 in., 0.875 in., 1.2 in., and 2 in. section bars were broken on 8 in., 12 in., 18 in., and 24 in. supports, and stress-strain dia-

Torsion tests were carried out on full diameter specimens with a gauge length of 8.25 in., and the stress was applied in inch-pounds.

Standard fatigue specimen and specimens having a V-notch in the centre were tested on a rotating beam machine and the results obtained showed the endurance limit to decrease with increased size of bar. In the case of the standard test-bar, the results obtained showed a higher endurance ratio, 60 to 61, than that normally obtained for cast iron. Tensile tests were carried out on test-bars machined from the various sections, after oil quenching from 830° C. and tempering at 450° C. The tensile strength was increased by heat-treatment, but the modulus of elasticity was not affected.

Growth tests were carried out on specimens machined to 4 in. by $\frac{1}{8}$ in. diameter, heated in an electric furnace at 815° C. for 1½ hours, cooled well below the critical range and then reheated. After each three cycles of heating, the specimens were measured. A total of 21 cycles was employed for this test. Values obtained were only comparative between the section sizes of permanent mould iron for the conditions used in the test. Similar sized specimens placed in a dilatometer gave coefficient of expansion values ranging from 6.65 to 7.62 $\times 10^{-6}$ for temperature ranges from 70° to 200° F. to 70° to 1,300° F.

The microstructure of the irons in their as-cast condition consists of a matrix of ferrite with some pearlite and fine graphite with a considerable amount of phosphide eutectic at the grain boundaries. On annealing, the graphite is finer and the ferrite size is smaller at the outside of the bar than at the centre, and the ferrite and graphite are finer in a smaller bar than in a larger bar. Only in the centre of the 2 in. bar does the graphite assume a small flake form. In the heat-treated bars the matrix consists of decomposed martensite. The microstructure of these permanent mould irons in the as-cast condition shows a progressive increase in grain size and graphite size, as the section is increased, but is not so marked as in bars cast in sand moulds due to the rapid extraction of heat through the metal mould, causing a smaller difference in the cooling rate between a 0.5 in. and a 2.0 in. bar. The matrix structure before and after annealing is practically identical for all section sizes. In view of all these facts, it is difficult to understand why such large differences in mechanical properties are obtained for different sections.

TABLE I.—PROPERTIES FOR PERMANENT MOULD CASTINGS, 0.5 TO 2.0 IN. DIAMETER.

Section Diameter, In.	0.5.	0.875.	1.2.	2.0.
Tensile strength, tons per sq. in.	22.3	15.2	14.3	10.1
Modulus of elasticity, lb. per sq. in.	19,530,000	17,570,000	13,600,000	11,980,000
Brinell hardness	153	163	168	164
Compressive strength, tons per sq. in.	55.5	50.0	53.4	44.5
Torsion, yield shear, tons per sq. in.	—	10.3	8.6	9.0
Torsion, rupture shear, tons per sq. in.	—	19.5	18.8	16.3
Torsion, modulus of elasticity, lb. per sq. in.	—	7,433,000	6,747,000	6,310,000
Transverse strength, lb. per sq. in.	606	1,863	2,670	8,200
Transverse deflection, in.	0.178	0.166	0.283	0.240
Modulus of rupture, tons per sq. in.	44.2	33.9	31.6	28.0
Bending, modulus of elasticity, lb. per sq. in.	19,600,000	16,940,000	14,380,000	11,870,000
Plastic work, %	57.1	40.1	37.7	30.5
Endurance limit, tons per sq. in.	14.3	8.9	8.7	6.0
Endurance limit notched bars, tons per sq. in.	<6.7	6.7	17.3	5.8
Heat-treated, tensile strength, tons per sq. in.	36.8	22.4	14.4	14.4
Heat-treated modulus of elasticity, lb. per sq. in.	19,200,000	17,400,000	13,360,000	10,950,000
Growth, increase in volume, % per cycle	0.133	0.170	0.180	0.330

In Table I are given the properties of permanent mould castings in sections of 0.5 to 2.0 in. diameter taken from production heats over a period of several months. Tensile strength tests were made on 0.75 in. diameter test-bars for the 1.2 in. and 2.0 in. section grams were drawn. The moduli were

computed where the load equalled 50% or less of the breaking load. The breaking energy in inch-pounds was computed for each bar from the stress-strain diagrams by obtaining the area under the stress-strain curves. The amount of plastic work is expressed as a percentage of the total work energy required to break the bar and is a measure of the toughness of the iron.

Fatigue Damage of Steel by Supplementary Tension-Impact Tests

By J. A. Kies and W. L. Holshouser

THE problem of detection of fatigue damage in parts in service, at present, consists in locating cracks, and a complete knowledge of the nature of the changes occurring in metals during repeated stress in the unsafe range seems to be required before a non-destructive field test can be devised which will foretell the coming of fatigue cracks. To develop such a test a long-range research is in progress at the National Bureau of Standards, and the use of impact tests as a possible means to detect fatigue cracking in the early stages of its progress is an essential part of this investigation. The present report deals with the conditions leading to the starting of fatigue cracks and with the effects resulting from such cracks.

In selecting impact testing as a means of evaluation of fatigue damage, it was considered that the results of such tests might be used to indicate such hypothetical progressive changes as the growth of systems of sub-microscopic flaws of unknown nature, and the building up of stresses to the point of near fracture in localized volume elements. Fatigue cracks are probably the sharpest kind of notch that it is possible to prepare, therefore it seems likely that very small fatigue cracks may cause a sharp loss in ductility of a structural member under shock loading. The well-known adverse effect of low temperatures on the impact resistance, particularly of ferritic steels, depends for its existence on the presence of a notch or its equivalent, and it appears important to include low-temperature impact tests in an investigation of fatigue damage in the hope of detecting cracks as early as possible.

A number of attempts to use impact tests to indicate progressive fatigue damage have been made, but having been done under conditions far from optimum, satisfactory results have not been attained. The uncertainties in stress distribution in transverse impact tests of notched specimens of rectangular sections probably outweigh and mask any differences caused

by previous fatigue stressing. Testing of smooth Haigh fatigue specimens in tension impact after repeated stressing and without further machining yield better results.

In this investigation, a chromium-molybdenum steel (S.A.E.-X4130) was used in the form of $\frac{1}{2}$ in. square hot-rolled bars. Before machining into test specimens having an overall length of $4\frac{1}{2}$ in. and a minimum diameter of 0.200 in., the bars were normalised at 900° C. and cooled in still air. The test portions of the specimens were finished by polishing with fine emery papers. Prior to impact testing, the specimens were separated into groups and were subjected to repeated stressing in a Haigh axial loading machine at room temperature and at unsafe ranges as follows: Group (a), 7 tons per sq. in. compression to 34.5 tons per sq. in. tension; group (b), 4.7 tons per sq. in. compression to 40 tons per sq. in. tension; group (c), 12 tons per sq. in. compression to 56.5 tons per sq. in. tension. All these ranges were sufficient to cause fatigue failure within 300,000 cycles. In addition, a group (d) was subjected to various numbers of repeated stress in the range 22.3 tons per sq. in. compression to 22.3 tons per sq. in. tension, which was sufficient to cause failure within 1,000,000 cycles.

The specimens were removed from the machine after various numbers of cycles, some before cracks were detected and some after cracks of various sizes had formed. Some specimens fracture completely in the fatigue machine. The tension-impact tests were made with a 224 ft.-lb. Charpy machine at room temperature and at $-33^{\circ} \pm 2$ C, the threaded end of the fatigue specimens being screwed into a special hole in the back of the pendulum. To obtain the low temperatures, the pendulum with specimen was immersed in a tank of 50% ethylene glycol; 50% water cooled by fragments of solid CO_2 which were added as required, and impact tests were completed for 3 to 5 secs. after removal of the specimen from the bath.

When mean tensile stresses and

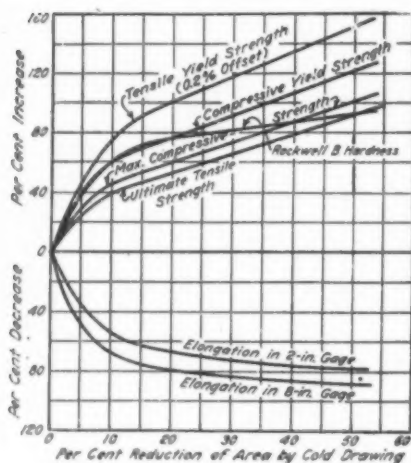
cyclic stress amplitudes high enough to produce appreciable permanent sets were used, there resulted losses in tension impact energy and elongation even though fatigue cracks were not detected. No appreciable loss in tension-impact resistance or elongation during impact, however, resulting from prior repeated overstress in fatigue, was noted in Haigh axial-loaded specimens in the pre-crack stage where the mean tensile stress and stress amplitudes were high enough to cause permanent sets of more than 0.01 in. during fatigue stressing. Such conditions are improbable in service and would be easily detected.

The formation of fatigue cracks, even the smallest detectable, were usually accompanied by substantial losses in tension-impact resistance. This was shown by plotting the average values for impact energy and elongation for all the groups tested against average values for maximum depth of penetration and for average values of the product of crack length and maximum depth of penetration. The first curve showed that there was no perceptible difference in the results at -33° C. and at room temperature for the smaller cracks and for cracks more than 0.65 mm. deep, the average impact resistance became less than half the room temperature value. This critical depth at which the low temperature effect was found corresponded to the second steep part of the curve, while the first steep portion corresponded to the advent of the smallest detectable crack.

The existence of a critical size at which the low temperature effect began to show itself was more clearly demonstrated when the factor of crack length, as dealt with in the second curve, was taken into account. For values of the product of crack length and maximum crack depth exceeding 0.70 sq. mm., the loss in impact resistance was more serious at -33° C. than at room temperature, and this critical size corresponded to the steepest portion of the curve with the exception of the initial drop. A curve of the relationship between average elongation and the product of crack length and maximum depth of penetration showed an initial steep drop in elongation with the first appearance of cracks, and a second steep drop for values of the product of 0.70 sq. mm. The critical crack size corresponded to crack areas of about 3% of the minimum cross-section of the specimen.

Effects of Cold Drawing on Welded Steel Tubing

THE effects of cold drawing on welded steel tubing are well known, but data giving these effects quantitatively are not readily available. As a result of a recent study made with SAE 1010 welded steel tubing at the engineering experimental station of the University of Illinois, the accompanying curves summarised quantitative data obtained. Thus, if the properties of normalised SAE 1010 welded steel tubing, free from cold working, are known or can be determined, the amount of cold drawing required to bring about a given increase in strength or hardness, and the concurrent decrease in ductility, as measured by percentage elongation, may be determined from these curves.



Curves indicating effect of cold-drawing on tensile yield strength, compressive yield strength, hardness, ultimate tensile strength, and ductility of SAE 1010 welded steel tubing.

The study has shown that the reduction of cross-sectional area of the metal in the tubing lends itself readily as a measure of cold working, because the reduction of external diameter required, hence the size of the die needed to produce a given reduction of area in a tubing of a certain size, may be readily determined if the change in wall thickness, occurring during cold drawing, is known. The effect on wall thickness during cold drawing is so small that it may be assumed to remain constant. Thus, the amount of cold working may be

controlled in production with no additional measurements or observations than those normally taken.

The increases in the tensile and compressive yield strengths (0.20% offset) of the SAE 1010 welded steel tubing were of the same order of magnitude for equal amounts of cold drawing up to 50% reduction of area, which was the maximum amount of cold drawing to which the tubing was subjected. This fact is important in the use of tubing for load-resisting members, and is in contrast with the effect of cold stretching, in which the compressive yield strength is increased much less than is the tensile yield strength.

Amounts of cold drawing of the SAE 1010 welded steel tubing up to about 10% reduction of area produced relatively large increases in strength and hardness, whereas additional amounts of cold drawing up to at least 50% reduction of area caused these properties to increase, but the increase was relatively less.

For amounts of cold drawing above approximately 10% reduction of area, the relation between the strength of the SAE 1010 welded steel tubing and the amount of cold drawing may be expressed by the general straight line equation, $S = kS_a(1 + R)$, where S is either the tensile or the compressive strength and either the ultimate or the yield strength, and S_a is the corresponding strength of the normalised tubing free from cold drawing.

A fairly definite relation existed for the cold-drawn SAE 1010 welded steel tubing between the ultimate tensile strength (which will here be denoted as T , since S in the foregoing equation

has several meanings) and the Rockwell B hardness number (R_b); namely,

$$T = \frac{4540}{146} = R_b$$

The tensile yield strength of the normalised SAE 1010 steel tubing free from cold working was about 0.70 of the ultimate tensile strength; for cold-drawn tubing in which the reduction of area of the metal in the tubing by cold drawing was greater than about 10%, the corresponding ratio was fairly constant at about 0.95.

The ductility of the SAE 1010 steel tubing as measured by the percentage elongation in an 8 in. gauge length in the tension test decreases rapidly with the amount of cold drawing up to about 10% reduction in area, and decreases much less rapidly for further amounts of cold drawing. The decrease in ductility is about 70% for 10% of cold drawing, and about 90% for 50% of cold drawing.

Substitute for 90 Copper 10 Tin Bronze Bearing Metal

THE necessity for adapting Swedish designs of the 40 mm. A.A. Bofors gun to standard alloys led to the quest for a substitute for the non-ferrous alloy containing between 7.5 and 11.0% of tin, formerly used, according to a paper on "Material Applications in Gun Manufacture," read before the 1943 convention of the American Society of Automobile Engineers.

The principal data on the chemical composition and physical properties of two such substitutes, both of them being copper-silicon alloys, compared with those of an ordinary 90 copper 10 tin bronze, are given in the following table:—

BRONZE AND COPPER-SILICON BEARINGS.

	9-10 Bronze.	Alloy B.	Alloy C.
Chemical limits or analysis—			
Si	—	3.24	4.03
Fe	0.10 max.	0.44	0.10
Su	7.5 to 11.0	0.68	—
Zn	1.5 to 4.5	5.1	0.30
Pb	0.3 max.	> 0.05	—
Ni	1.0 max.	> 0.05	—
Mn	—	0.02	1.05
Al	—	NH	—
F	0.05 max.	—	—
Tensile Properties—			
Ultimate strength, lb./sq. in.	40,000 min.	49,400	43,800
Yield point, lb./sq. in.	—	19,060	14,370
Elongation, %	20 min.	26.0	31.0
Reduction of area	—	38.5	42.3
Frictional Characteristics—			
Coefficient of friction	0.220—0.250	0.121—0.139	< 0.139
Wear factor	13.0 to 13.9	12.0 to 14.8	< 8.2
Seizure factor, lb./sq. in.	380	425	1,600

Comparative Quality of Converter Cast Steel

By C. E. Sims and F. B. Dahle

THE all-out war effort demands the utmost use of all available and suitable agencies of production, and an unprecedented demand for steel castings necessitates a greatly increased productive capacity, and one method by which capacity may rapidly be expanded is by the cupola-converter combination. Under modern conditions, the hot-blast cupola can produce an all-steel charge, and a charge low in phosphorus and sulphur can be selected. Control of the metal composition charged to the converter is therefore possible, and control of the operation, such as is provided by the photo-electric cell, can keep the nitrogen content of the blown metal to a minimum. Since converter cast steel can be made to the same chemical composition as acid open-hearth or acid electric-cast steel, and because of a lack of adequate existing data, tests were carried out to compare the engineering properties of grade B converter cast steel in comparison with similar steels made by other processes.

Steels made by the acid open-hearth, basic open-hearth, acid electric, basic electric, "Triplex" (cupola-converter-electric), and side-blown converter were used. The composition of the steels were very similar, the carbon varying from 0.21 to 0.35%, the manganese from 0.5 to 0.88%, and the silicon from 0.28 to 0.55%, and all came within the grade B specification. The basic open-hearth steels were lower in phosphorus than any of the others, while the converter steels as a class were slightly higher in phosphorus than the acid open-hearth and electric steels. The basic open-hearth steels also had a slight advantage in sulphur content, but the desulphurising treatment of the cupola metal put the converter steels on a par with the acid electric and acid open-hearth steels in respect of this impurity. The Triplex steels had the highest nitrogen content with an average of about 0.011%, the straight converter steels and acid electric steels were in the same range of 0.006 to 0.01%, while the open-hearth steels had a still lower range of 0.004 to 0.006%. The various steels were tested after normalising at 900° C. and after normalising at 900° C.,

followed by annealing at 400° C. Micro-examination made to determine the nature of the inclusions and the grain size, showed that, with the exception of the high sulphur steels which had more sulphide inclusion than those low in sulphur, there was no marked difference in the amount of the inclusions present. The type of inclusion was found to coincide with the deoxidation practice and particularly with the use of aluminium.

steels were deoxidised with aluminium, and the effect of aluminium is well known, no significance is given to the method of production. Steels treated with titanium showed no advantage over those without a special deoxidiser, but titanium produced some grain refinement, but not so much as aluminium. Low temperature annealing caused a slight average drop in the yield strength, but had no effect on the tensile strength. Hydrogen embrittlement, as indicated by the improvement of ductility after annealing, was not pronounced in the converter steels, although some trouble with hydrogen was not uncommon in some of the other steels, particularly the basic

TABLE I.—AVERAGE RESULTS OF MECHANICAL PROPERTIES OF GRADE "B" CAST STEELS.

Steel.	Yield Point, Tons per sq. in.		Tensile Strength, Tons per sq. in.		Elongation, %		Impact Strength, Ft./lb., Normalized and Annealed.		Brimell Hard- ness, Normal- ized and Annealed.	A.S.T.M. Grain Size, Normal- ized and Annealed.
	Normal- ized.	Normal- ized and Annealed.	Normal- ized.	Normal- ized and Annealed.	Normal- ized.	Normal- ized and Annealed.	Isod.	Charpy.		
Acid open-hearth.	21.3	20.4	35.1	35.7	31	31	27.5	21	155	6 to 8
Basic open-hearth.	20.9	20.8	35.1	35.4	31	32	33	25	154	6 to 7
Acid electric.	22.6	21.2	35.6	35.4	29.5	29.5	27	21	156	7 to 8
Basic electric.	26.3	27.0	41.1	41.7	20.0	23.0	19	12	188	7 to 8
Converter acid (Triplex)	23.1	23.7	38.3	38.7	24.0	24.5	29	16	160	6 to 8
Converter	22.8	22.5	35.4	35.5	26.0	30.0	36	21	155	7 to 8

TABLE II.—AVERAGE RESULTS OF LOW-TEMPERATURE NOTCHED-BAR IMPACT PROPERTIES OF GRADE "B" CAST STEELS.

Steel.	Single Width Charpy (Keyhole Notch) Impact Strength, Ft./lb.						
	212° F.	70° F.	32° F.	0° F.	-20° F.	-40° F.	-60° F.
Acid open hearth	28	21	17	14.5	9	6	1.5
Basic open hearth	34	25	20	18.5	15.0	6.5	4.5
Acid electric	31.5	26.5	22	16	14	6	4.5
Basic electric	14	12	10	7.25	5.75	4.25	3.0
Converter acid electric (Triplex)	18.5	16.5	13	11	10.5	10	8
Converter	24.5	21.5	17.5	16	14	11	12

TABLE III.—FATIGUE PROPERTIES OF GRADE "B" CAST STEELS.

Steel.	Endurance Limit, Tons per sq. in.			Endurance Ratio,		
	Unnotched Room Temperature.	Notched Room Temperature.	Notched -40° F.	Unnotched Room Temperature.	Notched Room Temperature.	Notched -40° F.
Acid open hearth	17.0	9.8	—	51	29.5	—
Basic open hearth	16.6	9.8	—	40	29	—
Acid electric	17.9	11.1	10.7	50	31	30
Basic electric	17.0	12.0	—	45	29	—
Triplex	15.4	11.6	—	40	30	—
Converter	14.7	10.7	9.8	43	31	28.5

In Table I are given the average mechanical properties, together with the grain size of the various steels. These results show that at room temperature the mechanical properties are entirely normal for grade B cast steel, and vary only with the composition and type of inclusions without regard to the method of manufacture. The converter steels, as a group, had the best normal temperature notched-bar impact properties, but as these

open-hearth and acid and basic-electric steels.

Average results of low temperature notched-bar impact tests as carried out on single-width Charpy test-pieces are given in Table II. From these results it is seen that the impact values gradually decrease with drop in temperature until suddenly they become very erratic or drop to a much lower value, and it is this falling-off, where steels change from a relatively tough

to a brittle material that it is important to determine. In general, these low-temperature notched-bar impact values appear to show a distinct advantage for converter (including Triplex) steel, although the evidence of certain other steels indicate that the melting medium is of secondary importance to deoxidation practice. An exception might be made in the case of the basic open-hearth furnace, if it can be shown that low phosphorus content, which is more or less inherent to the process, is responsible for the good properties shown by those steels. Tests carried out with double-width Charpy test-pieces showed, in general, the first sign of brittleness to occur at a slightly higher temperature.

The effect of strain-ageing on the notch-bar impact properties of the various steels were also determined when it was found that steels having no strong deoxidation treatment were, as a rule, much more susceptible to ageing after cold work than were steels fully deoxidised, and that the former steels showed substantially larger decreases in impact strength after ageing

than did the latter steels. A limited number of standard fatigue tests showed a superiority in endurance ratio for the acid open-hearth and electric steels, Table III, but notched fatigue tests showed a notable similarity for all the steels.

The tests, in general, showed no evidence to favour one process over another, except that the basic open-hearth gave better phosphorus control. Mechanical or engineering properties of all the steels were governed by composition and by deoxidation rather than by the melting process. When low-temperature shock resistance is required, a low-temperature notched-bar impact test is suggested for acceptance, and it is considered that, if this were done, steels should be accepted, or rejected on this test rather than on the melting process used, and that some steels now being accepted, but not of good low-temperature toughness, would be excluded and much good converter steel would be made available. With proper deoxidation, all the processes can be used to make steel of the quality demanded for war purposes.

Arc Welding of Magnesium Aircraft Structures

By V. H. Pavlecka and J. K. Northrop

DURING the last decade, monocoque or semi-monocoque aircraft structures, in which all or a substantial portion of the structure load is carried in the skin, have come into general favour among aeroplane designers. The best and most efficient materials for use in pure monocoque construction are those having a low specific gravity and a relatively high modulus of elasticity, in order that the material may have high compressive strength before buckling occurs. Certain plywood combinations, if uniform in quality and readily available in quantity, prove of the best structural value, but in comparison certain metals and alloys are available in much larger quantities and their qualities can be kept exceedingly uniform.

In considering metals for stressed skin structures, steel, although very efficient for structures of a semi-monocoque type, is unsuitable for monocoque structure due to its weight and its tendency to buckle when used in thin sheets. Flat aluminium sheet must also be regarded as having a

higher density than desirable and is rarely used without some internal stiffening of strips or corrugations. Also, while spot welding has been developed to an excellent degree of reliability for many of the aluminium alloys, an exacting technique is required in its use, and many joints must be made where the physical limits of spot-welding equipment do not permit its use. Magnesium and its alloys, as the lightest of generally available structural materials, are considered the most suitable materials, as they have a weight less than two-thirds the weight of aluminium, and are not much over one-fifth as heavy as steel, and have a relative stiffness, for a given weight, of 2.5 times that of aluminium, and 19.5 times that of steel.

When it was decided that magnesium was the most suitable material to use for aircraft structures, the best method of fabrication for this metal and its alloys had to be developed. Consideration of riveting showed that rivets of magnesium alloy work-hardened so rapidly during driving as to prove impractical, so that other

materials had to be used for rivets in assembling magnesium parts. Also ideal surface smoothness could not be attained by lap-joints whether riveted or spot-welded, particularly in view of the comparatively thick sheets used in pure monocoque design. Gas welding could only be accomplished under the protection of a heavy flux, due to the extreme affinity of magnesium for oxygen and nitrogen, particularly at elevated temperatures, and successful fluxes were of an extremely corrosive nature, and rapidly attacked the resultant magnesium assembly, if the slightest contamination remained in the weld.

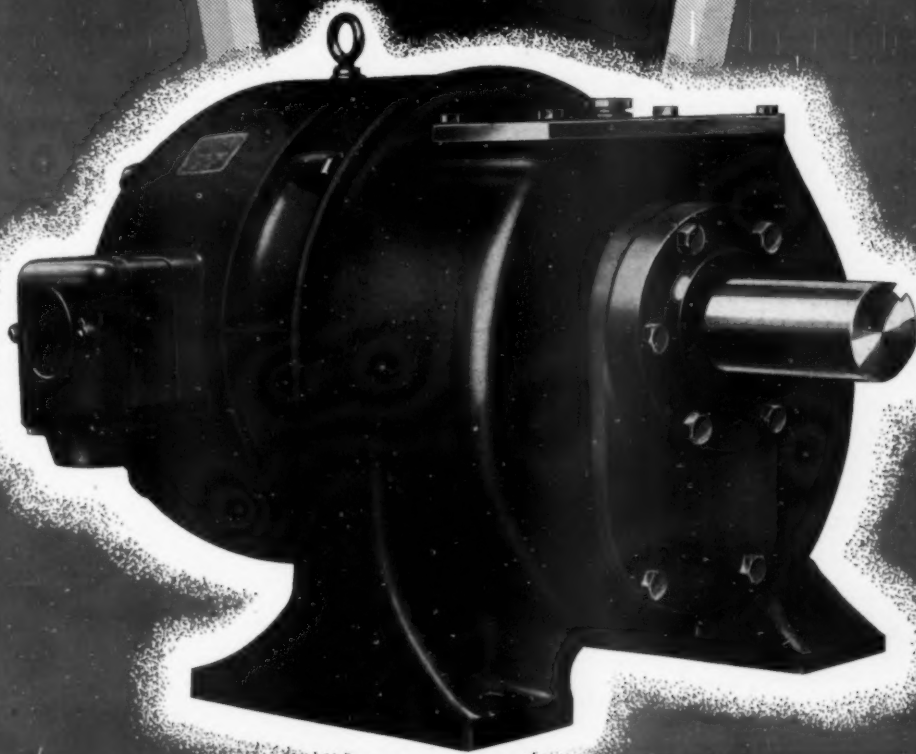
With regard to electric arc welding, a very large number of preliminary experiments were made with all possible variations in alternating and direct currents, polarity, types and materials for electrodes, and fluxes. Fluxes were soon abandoned from considerations of corrosion, and numerous efforts were made to weld, using various types of blanketing gases either in an enclosed space or allowed to flow over the work from the vicinity of the electrode. Good results were obtained when an arc was struck between the work and a magnesium electrode supported in a hollow receptacle through which helium under low pressure was allowed to flow into the weld area, and this success led to the development of the Heliarc method, where a tungsten electrode is used in a helium atmosphere.

The helium arc method of electric welding of magnesium, useful with all standard direct-current welding machines, consists in striking an arc between the work and a tungsten electrode, simultaneously feeding helium gas to the weld area through an annular nozzle surrounding the electrode, and feeding the additional weld material required for the joint into the arc from an uncoated welding rod of substantially the same material as the work. The flow of helium fed to the work area at 0.25 lb. to 0.5 lb. per sq. in. is controlled by a valve on the torch handle which is opened by the operator just before the arc is struck, and held open during the welding process, which is carried out using reversed polarity.

The quality of the weld obtained is high, the strength of the joint varying from 80 to over 100% of the parent material, depending on the alloy and the welding conditions, and there seems to be no limitations in the type of joint which can be made—butt, lap,

(Continued on page 122).

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Are Welding of Magnesium Aircraft Structures

(Continued from page 112).

tee, corner, and angle joints being made with equal facility. The helium blanket completely eliminates the use of any flux in the joint, and while minute quantities of tungsten are present in the weld, there are no adverse corrosive effects therefrom. The weld metal actually appears somewhat more corrosion-resistant than the parent metal, there being a slight electrolytic balance which causes corrosion, if it appears at all, to be present in the sheet adjacent to the weld rather than in the weld itself, but this effect is so small, however, as to be negligible for all practical purposes. Welds can be made with equal facility in rolled, cast, extruded and forged parts, and some experiments have been made where cast and rolled or extruded parts have been welded together. The seams, fusion welded by the helium arc process, are distinguished by their metallurgical purity, homogeneity, and absence of inclusions.

In almost all welding, a certain amount of distortion must be allowed for, and magnesium is no exception to

this rule, and this phenomenon was the cause of some of the most persistent and annoying difficulties in the early stages of the development of helium arc welding. A considerable number of tests led to making proper allowances in length for shrinkage, and this difficulty was solved satisfactorily, as far as dimensional control was concerned, but shape distortion, which manifests itself as buckling of the monocoque shell, particularly at those places where the curvature is not pronounced, proved much more difficult to control. As the results of experiments, however, a simple and satisfactory method was developed dealing with buckling distortion, which does not harm the metal either internally or externally. By this method, heat and pressure are applied to the buckled surfaces after welding through the use of ironing pads, which relieve the internal strain in the sheet and give a smooth non-buckled surface.

To make certain that no excessive locked-in strains are set up in helium arc-welded structures, experiments were carried out to obtain the absolute value of internal stresses in magnesium alloys induced by welding, and as these stresses were found to be of the order of 1,000 lb. per sq. in. maximum they

can have little effect on the welded structure. This is probably due to the relatively low modulus of elasticity and low yield strength of magnesium alloys, both of which physical properties tend to adjust metal structure readily to any internally imposed strains from welding.

The amount of welding that can be carried out in magnesium aircraft structures is not indiscriminate. Proportioning of the welded seams to the load carried through them and selecting the type of weld to fit the best conditions of elastic flexure of the structure are the two recognised principles for successful electric arc-welding application, and must be observed if satisfactory results are to be obtained. While there is some slight economic advantage in the arc welding of magnesium aircraft structures when compared with riveting, the most valuable contribution gained by such a method of fabrication is in the reduction in drag of the finished aeroplane. This is due to monocoque welded magnesium structures being designed with comparatively thick skins which do not buckle locally within the normal range of flight loads, and also due to the smooth surface finish obtained.

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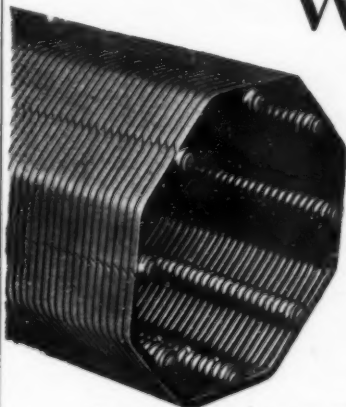
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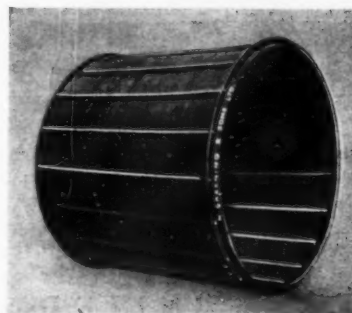
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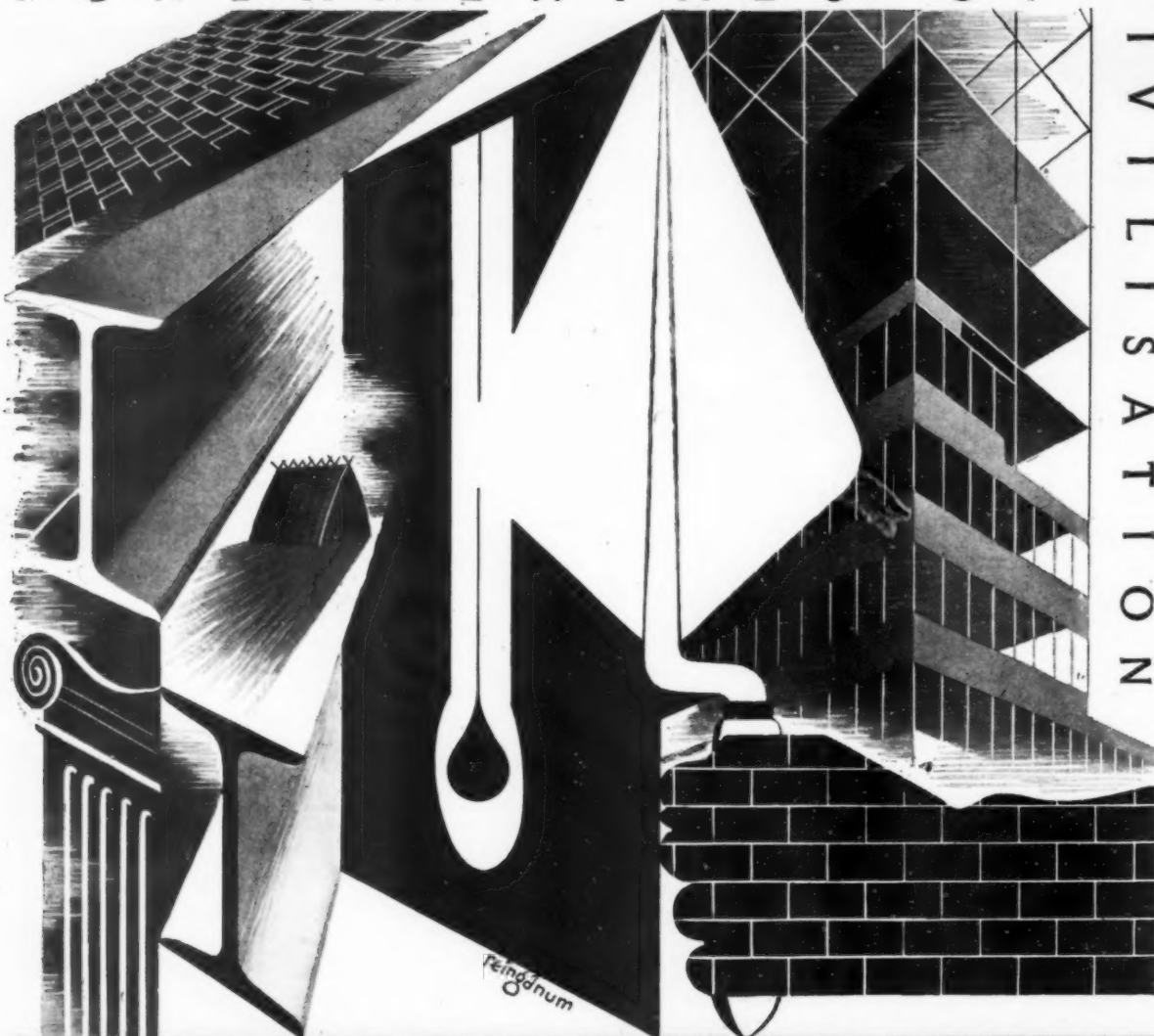


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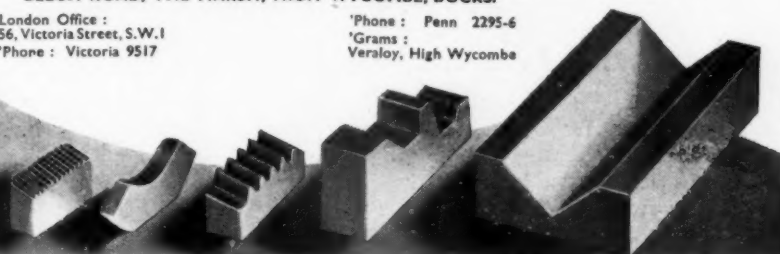
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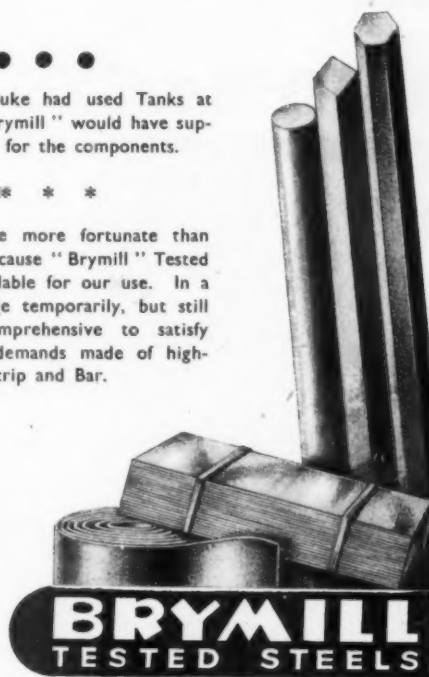


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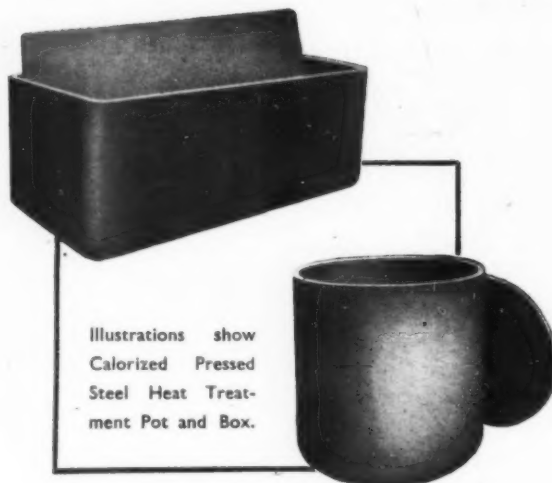
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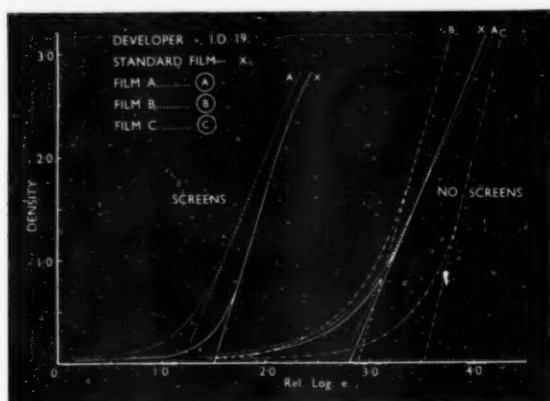
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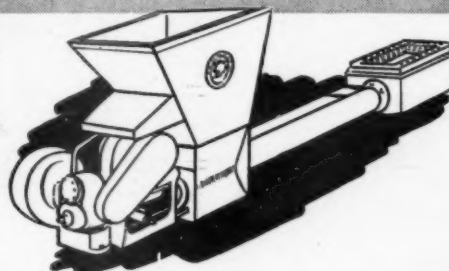
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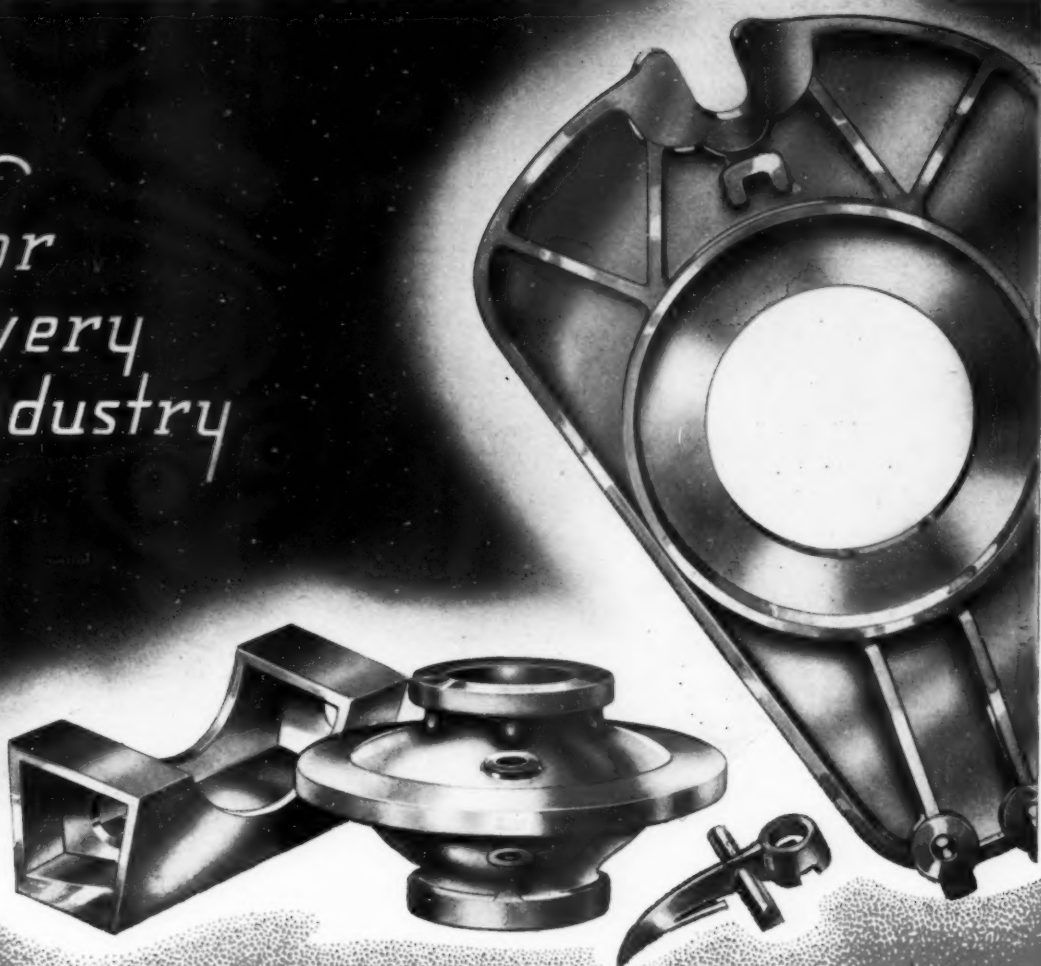
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